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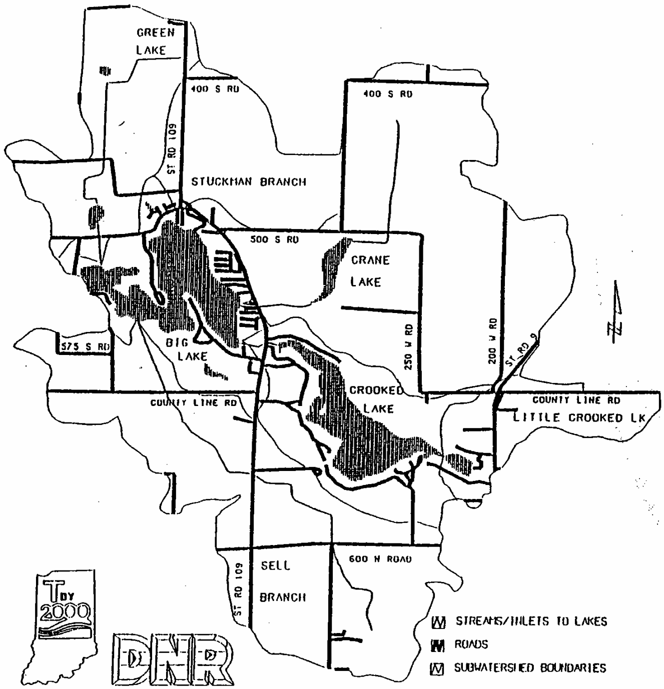
A PRELIMINARY ASSESSMENT OF BIG LAKE, NOBLE COUNTY (1992-1995)



A Report for the Big Lake Association

by
Indiana Department of Natural Resources
Division of Soil Conservation
Lake and River Enhancement Program

July 1995

A PRELIMINARY ASSESSMENT OF BIG LAKE, NOBLE COUNTY (1992-1995)

FINAL REPORT

July 1995

Presented to:

The Indiana Lake and River Enhancement Program
Indianapolis, Indiana 46204

Prepared for:

The Big Lake Association

By:

Indiana Department of Natural Resources
Division of Soil Conservation

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EXECUTIVE SUMMARY

This report gives the results of a preliminary study of the water quality and watershed status of Big Lake in Noble and Whitley counties. Further study, management alternatives, and recommendations for lake restoration are presented.

Conclusions

Condition of Big Lake and Watershed

1. During all summers for which data were available (1963-1992), Big Lake chemical stratification occured between 5 and 20 feet in depth. Since 1974, the depth below which oxygen levels (<4 mg/L) would not support most life during stratification ranged from 10 to 13 feet. In 1963, oxygen levels did not drop below critical levels until 18 feet.

2. Bluegreen algae which are notorious for causing algal blooms in eutrophic (nutrient enriched) lakes constituted 98 to 99 percent of the phytoplankton collected in 1990 and 1992. Other organisms found in the plankton were also indicative of lakes which are receiving moderately high levels of nutrient runoff, soil erosion, and sewage inputs.

3. Water clarity in Big Lake appeared to cycle from "good" in 1963, 1990, 1993, and 1994 to "poor" in 1974, 1980, 1991, and 1992. High water clarity was somewhat associated with drier years. In most years, light levels would limit beneficial algae and green plants to depths less than 6 to 9 feet.

4. Original diversity of native plant species has decreased by 40 percent over the past 30 years. Exotic species, including curly-leafed pondweed and watermilfoil, dominated the current stand of plants along shorelines in front of residential areas.

5. Nitrogen levels have tripled and phosphorus levels have quadrupled over the past 20 years. While phosphorus concentrations and chlorophyll a levels in shallower water (epilimnion) have stabilized or dropped in recent years, nutrients in deeper water (hypolimnion) have increased since 1974. These trends indicated a possible decrease in nutrient inputs from the watershed, but an increased internal loading from nutrients stored in the sediment.

6. Since 1974, Big Lake has deteriorated from a Class II (intermediate quality) lake at 38 points to a Class III (lowest quality) lake at 64 points on the IDEM Eutrophication Index (EI). Degradation of lake water quality has accelerated dramatically since 1990, according to EI scores.

7. Nutrient and sediment inflow from tributaries increased up to six times baseflow levels during stormflow. Compared to the other four inlets, Stuckman Branch contained the highest amount of each nonpoint source pollutant (nitrogen, phosphorus, and suspended solids) during stormflow, with the exception of an equivalent amount of total phosphorus coming from the Crane Lake subwatershed. Data from 1991 indicated that most of the phosphorus in the deeper water (hypolimnion) of Crane Lake was in soluble form. This finding may explain why outlets from Crane and Green Lakes contributed phosphorus to Big Lake, even though the smaller lakes on the tributaries were apparently acting as settling basins.

8. Modelling indicated that the vast majority (88 percent) of phosphorus from the watershed originated from agricultural land, simply because the areal extent of the agricultural land was relatively large and consisted mostly of row crop agriculture. The second highest source was from septic systems at 5.6 percent. According to the model, the Crane and Sell subwatersheds theoretically contribute the highest phosphorus load to Big Lake.

Models are useful for prioritizing areas for future study and are not designed to predict actual contributions. A number of variables were not accounted for in the model, such as weather, row cropping practices, effects of livestock confinement facilities, transport rates of sediment and nutrients in stream channels, and nutrient leaching rates through different soil types.

Recommendations

Improvement of the lake's water quality will require management of the lake and its watershed. Big Lake exhibited characteristics which will require a comprehensive approach to restoration and management.

In-lake Restoration

Lake restoration measures will improve the immediate quality of the lake, but must be coupled with watershed management in order to obtain long-term protection and enhancement of the resource. Some of the following suggestions require more focused study for proper design of the treatments. Restoration of Big Lake could include:

Control of internal phosphorus loading from sediment sources by sealing with alum, binding nutrients through oxidation or skimming sediment with appropriate disposal. Sediment disturbance due to construction or recreation should be minimized. Data from Crane Lake also indicated 91 percent of the total phosphorus in this tributary lake was also associated with deeper water and sediments.

Chemical control of exotic aquatic plants in nearshore areas along residential east and north sides of the lake may improve conditions for recreation. If mechanical harvesting is conducted, plant material must be removed and disposed of away from wetland and lake areas. Larger stands of native plants along the western basin should be protected as a hedge against further invasion of exotic plants and as remaining habitat for fish and wildlife.

~~Encouraging anglers to target species other than largemouth bass and imposing catch limits for a period of time could improve the future fishery for large adult bass. Restocking northern pike could control rough fish and shift pressure away from bass. Educational programs to enhance angler interest in pike fishing would be necessary~~.

Watershed Management Plan

Watershed management plans should be targeted to sources which contribute the highest levels of nutrients and sediment to the lake. The most applicable watershed management practices include:

Movement of soils and associated nutrients should be limited by vegetative buffer strips and conservation tillage. The Stuckman Branch subwatershed appearantly contributed sediment and nutrients during storm events out of proportion to what would be expected given land use and soil erosivity.

Streambank stabilization and retention basin projects may be useful in limiting erosion and transport of sediment within waterways. Stuckman Branch and Sell Branch waterways may benefit most from such projects.

Routine maintenance of current septic systems is essential for preventing further degradation of lake water quality. Saturated soils and residential development limit potential for repairing current septic systems or siting new septic absorption fields. The lake association may wish to continue negotiations for developing sewage lines and a treatment plant.

Where possible, physical connections between different types of wildlife habitat should be protected or restored. Wetlands adjacent to forested areas and waterways are particularly important for providing food and shelter to wildlife. Natural areas in the Sell Branch subwatershed north of C.R. 600N and along Airport Road are candidates for restoration and enhancement.

Forested areas and wetlands immediately adjacent to Big Lake are important for trapping nutrients and protecting the shoreline from erosion. Planting of native ornamental trees and shrubs between residential properties and the lakeshore can improve habitat and esthetic values of the property. Wetland areas around the Green Lake outlet and idle land to the southeast of Green Lake should be protected from disturbance.

Section 1. INTRODUCTION

This report documents the findings and recommendations from a preliminary investigation of Big Lake in Noble County, Indiana. The preliminary investigation was conducted under the auspices of the T-by-2000 Lake and River Enhancement Program (LARE), Division of Soil Conservation, Indiana Department of Natural Resources. The investigation was conducted by LARE staff in cooperation with the Big Lake Association.

The purpose of the preliminary investigation was to characterize the water quality of Big Lake and conditions in the watershed and to identify problems affecting lake water quality, the sources of those problems, and potential solutions. This final report provides the Big Lake Association with a baseline against which to evaluate future lake and watershed management changes, as well as a framework within which to begin managing and protecting Big Lake.

1.1 BIG LAKE

Big Lake is a 228 acre lake located immediately west of State Road 109, approximately seven miles north of Columbia City, in the southwest corner of Noble County, Indiana (Figure 1.1). The majority of the lake and contributing watershed is located in Noble County with the remainder lying in Whitley County. The areal extent of the Big Lake watershed is 8.89 square miles (Clark, 1980). In 1987, Big Lake had a maximum depth of 70 feet, an average depth of 25 feet, and a volume of 1.83 billion gallons of water (5,616 acre feet) (Pearson, 1987).

Big Lake is located within the Wabash River drainage basin, and together with Crooked Lake, forms the headwaters of the Tippecanoe River. Big Lake receives runoff from five major inlets plus direct overland flow from the surrounding residential shoreland. The major tributaries to Big Lake are the Sell Branch inlet entering from the southeast and the Crane Lake inlet entering from the northeast. Minor tributaries include inflows from Green Lake to the west, nearby Crooked Lake to the east, and the Stuckman drain system located to the north.

The entire Big Lake watershed, including the Crooked Lake subwatershed, encompasses 6,026 acres which consists of 424 acres of water, including Big Lake and three other waterbodies: Crooked Lake, Crane Lake, and Green Lake (Table 1.1). The watershed is primarily agricultural and is characterized by gently rolling areas and low morainal ridges. This study focuses only on the Big Lake watershed which contains 5,009 acres, excluding the Crooked Lake watershed.

Figure 1.1. Map of Big Lake watershed in Noble and Whitley counties, showing streams, roads, and subwatershed boundaries.

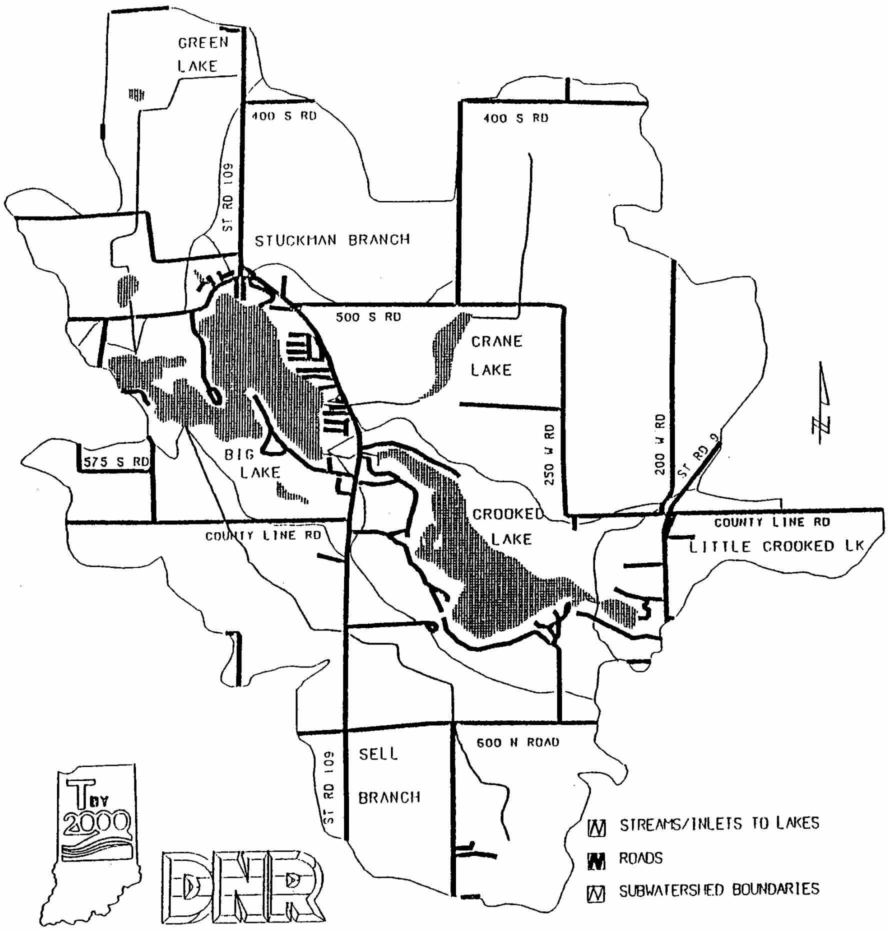


Table 1.1. Subwatershed land and water areas within the Big Lake watershed.

Subwatershed	Land (acres)	Water (acres)	Subtotal (acres)
Crane Lake	1651	27	
unnamed lake		3	1681
Sell Branch	1510	0	1510
Green Lake	629	7	
Harroff Lake		3	639
Stuckman	531	0	531
Big Lake	436	228	648
Subtotal	4757	268	5009
Crooked Lake Watershed:			
Crooked Lake	490	160	650
Little Crooked	355	12	367
Subtotal	845	172	1017
TOTAL Watershed	5602	424	6026

Big Lake is used primarily for recreation, including boating, fishing, and swimming. A public access site, operated by the Indiana Department of Natural Resources, is located on the southeast shore adjacent to Lakeshore Drive. The site was developed in 1986 (Pearson, 1987). Boat speeds are regulated on the lake to allow boating above 10 mph between the hours of 1pm to 4pm every day. The mandatory 200 foot clearance permits higher speed boating only in the eastern basin.

Much of the Big Lake shoreline is occupied by single family residential dwellings with the exception of wetland areas located along the north shore of the western basin and the southern shore of the middle basin, which are largely uninhabited. According to the Noble County Planning Commission, Big Lake has the greatest number of homes of any lake in Noble County at 461. Approximately 80 percent of the homes are occupied year round (B. Shellman, pers. comm.). Although little new construction has occurred in recent years, a development of 30 houses has been proposed for a 30-acre tract of land immediately west of the Sell Branch outlet along Big Lake (Michael Martin, Big Lake Association, pers. comm.).

Big Lake was known as Tippecanoe Lake as late as 1923 and was once the largest lake in Noble County with a length of nearly one and one-half miles and a width of over one-half mile. The bottom of the lake was reported to be composed of muck, sand, and marl (Blatchley, 1901). Big Lake was once 320 to 480 acres in size (Outdoor Indiana, 1950).

Human and natural action has reduced the aerial extent and volume of the lake. Lake area decreased by up to 40 percent in the early 1900s as a result of dredging and draining in the vicinity of the lake's outlet (Stangland Ditch). As of 1987, the aerial extent of the lake was only 228 acres. Most of the residential development around the lake occurred in the 1950s and 1960s. The legal lake level for Big Lake was set in 1956 at an elevation of 898.1 feet, N.G.V.D., and is now controlled by a sheet piling dam constructed in 1987. Before installation of the dam, the water renewal time for the lake was approximately 1 year and 9 days.

No information is available on the depth of Big Lake prior to European settlement. An article in Outdoor Indiana (1950) reported that "the present depth averages 40 feet and the maximum depth is 103 feet." However, a U.S.G.S. map, dated 1956, indicated a maximum depth of 70 feet and an average depth of 25 feet. Considering that lake depth probabably did not change by 30 feet in six years, the report in Outdoor Indiana may be a close estimate of depths at European settlement. Lake depth has not been mapped since that time, but all sets of more recent limnological data suggest a maximum depth of 70-72 feet.

Lake ecology has changed since the early 1900s. Prior to significant development, vegetation was sparse over the mostly marl and sand bottom, but in some areas, the lake also supported lush stands of cattail, wild rice, and reeds (Outdoor Indiana, 1950). Like several other lakes in the region, Big Lake used to harbor a population of cisco. Exotic species of aquatic plants and fish have invaded the lake in recent decades.

1.2 NATURE OF THE PROBLEM

In 1991, the Big Lake Association contacted the IDNR Division of Soil Conservation to become involved with in the T-by-2000 LARE program. Members of the Big Lake Association expressed concern over the general quality of Big Lake and the impact of rising year-round residences on the lake. The property owners did not sense dramatic changes or significant problems at Big Lake, but rather were interested in defining the lake's present rate of eutrophication and assessing the need for actions to ensure the future of this resource.

Big Lake lies in close proximity to Crooked Lake, a Class I (highest quality) lake. Big Lake receives the outflow of Crooked Lake, but does not exhibit the same high quality characteristics of Crooked Lake. Big Lake is reportedly prone to nuisance blue-green algae blooms during the summer months and is subject to intense high speed boating on weekends. Macrophyte growth is extensive along much of the shoreline, but does not significantly impair lake uses. Members of the Big Lake Association expressed special concern over the runoff entering the lake through Stuckman Branch. They felt that problems in this inlet had been exacerbated by the construction of State Road 109.

1.3 STUDY OBJECTIVES

The objectives of this preliminary investigation were to: 1) characterize the current condition of Big Lake and its watershed; and 2) identify problems affecting the water quality of Big Lake, the sources of problems, and potential solutions.

The investigation included a series of tasks to evaluate biological, chemical, and physical parameters in both the lake and watershed. The results of the preliminary investigation were intended to provide the Big Lake Association with a baseline for evaluating future lake and watershed changes and a framework within which to begin managing and protecting Big Lake.

It must be kept in mind that the investigation was preliminary in scope. Therefore, the main purpose of the results is to provide baseline data and lend direction to future actions. More data collection and evaluation may be needed before expensive restoration measures are pursued.

SECTION 2. METHODS OF DATA COLLECTION AND ANALYSIS

Data collection and analysis were conducted according to standard limnological procedures. Where possible, historical information was obtained for comparison with current status of the lake and watershed.

2.1 HISTORICAL DATA

Historical data pertaining to Big Lake and its watershed were obtained via literature searches and contacts with other government agencies. Information regarding water quality, fisheries, aquatic plants, soils, land use, and population were sought. Where possible, historical data were compiled into the project database to compare with current data and note trends. Contacts made for historical information include government, university, and local resources (Table 2.1).

Table 2.1. Sources of historical information on Big Lake.

- Indiana University Library
- Indiana State Library
- Indiana Department of Natural Resources
  - Division of Water
  - Division of Fish and Wildlife
  - Division of Nature Preserves
- Indiana Department of Environmental Management
- Noble County Health Department
- Noble County Planning Commission
- Noble County Soil and Water Conservation District

2.2 SOIL LIMITATIONS AND LAND USE

Land uses in the Big Lake watershed were identified and delineated using a combination of the following resources: 1) U.S. Geological Survey (USGS) 7.5 minute topographic maps; 2) aerial photographs; 3) interviews with Whitley County Engineer and Noble County Surveyor; and 4) on-site inventory. The watershed was delineated using topographic maps and surveyor interviews. Historical land use, crop, and tillage trends were also reviewed. Aerial photographs were used to delineate land uses in seven categories (Table 2.2). Potential or current land use activities impacting the water quality of Big Lake were identified.

Soil surveys were used to evaluate soil associations and soil types found in the watershed. The amount and locations of highly erodible soils (HEL) were determined. Combining the soil information with land use information, the areas having highest potential for erosion were evaluated.

Table 2.2. Land use categories for delineation of Big Lake watershed.

Classification
Row crop
Grazing
Lake
Wetland
Forest
Residential
Idle
Non-study area

2.3 LAKE SURVEY

Measurements of various physical, chemical, and biological components were taken to describe the lake's status.

2.3.1 CHEMICAL MEASUREMENTS

Water samples and in-lake measurements were obtained on 25 June 1991 at two in-lake stations. All available historical data were obtained at the deepest point in the lake. Therefore, station 1 was located at the deepest point in the eastern (main) basin and station 2 was located at the deepest point in the western (third) basin (Figure 2.1). Profiles of temperature and dissolved oxygen at each station were obtained with a YSI Model 51B Dissolved Oxygen Meter and probe. Epilimnetic and hypolimnetic measurements for pH were made with a Jenco Analog pH Meter equipped with an Orion field pH probe. Secchi disk transparency was measured on the shaded side of the boat. The average of the depth at which the disk disappeared and the depth at which the disk reappeared was reported as the Secchi disk depth.

At each in-lake station, water samples were collected from the epilimnion (3 feet from surface) and hypolimnion (3 feet from bottom) with a 2.2L clear acrylic Kemmerer bottle. Pre-preserved bottles supplied by the laboratory were filled directly from the Kemmerer bottle for nutrient analysis. Duplicate samples from a separate Kemmerer bottle grab were collected from the epilimnion at Station 1 for quality assurance. Deionized water was used to prepare a field blank for each nutrient parameter sampled. Samples were stored on ice in a cooler and delivered to the laboratory within 24 hours after collection. Table 2.3 lists the measured parameters and the laboratory methods used for analysis of the samples.

Figure 2.1. Map of two in-lake sampling sites (deepest point of eastern and western basins) on Big Lake in Noble and Whitley counties.

Table 2.3. Chemical parameters measured and methods.

Total Phosphorus	Standard Methods, 4500-P
Orthophosphate	Standard Methods, 4500-P
Nitrate Nitrogen	Standard Methods, 4500-NO3 D.
Ammonia Nitrogen	Standard Methods, 4500-N
Total Kjeldahl Nitrogen	Standard Methods, 4500-Norg B.

2.3.2 BIOLOGICAL MEASUREMENTS

Plankton samples were collected at Station 1 and Station 2 on 25 June 1992 with a conical-style one to five ratio plankton net with a 12 inch diameter net opening and a net mesh size of 63 microns. At each station the net was towed vertically from the beginning of the metalimnion to the surface. Plankton samples were preserved with Lugol's solution at a rate of 1 mL per 100 mL of sample. Plankton samples were identified to genus and enumerated in the laboratory using a Sedgwick Rafter Cell counting technique (Wetzel and Likens, 1991).

On 14 June 1992 aquatic macrophytes were surveyed qualitatively by boat reconnaissance of the shore areas. Macrophyte abundance and dominant types were noted. Plants were identified in the field when possible. Species requiring further identification were collected for later examination. An aquatic plant map was produced detailing types and locations of plants.

2.3.3 TROPHIC STATE ASSESSMENT

Chemical and biological water quality parameters obtained during the 25 June 1992 sampling event were used to calculate a eutrophication index for Big Lake using the Indiana State Board of Health (ISBH) Lake Eutrophication Index (IDEM, 1986). The current eutrophication index was compared to previous index calculations for evaluation of trends.

A mathematical phosphorus loading model was used to calculate an estimate of phosphorus loading from each subwatershed and to predict in-lake phosphorus concentration.

2.4 WATERSHED SURVEY

Biological, physical, and chemical characteristics of the tributaries of Big Lake were measured to identify sources of pollution for the lake. Unit area loading models were used to determine approximate phosphorus contribution from land use types and subwatersheds.

2.4.1 TRIBUTARY WATER QUALITY

Historical data on the tributaries feeding into Big Lake were collected via literature search and analyzed. In addition, baseflow and stormflow grab samples were collected from each of the five tributaries to Big Lake on 8 April 1992 and 17 June 1992, respectively. Samples were analyzed for total phosphorus, total suspended solids, and total Kjeldahl nitrogen. Pre-preserved bottles from the laboratory were filled directly from the tributary. A duplicate sample for each parameter was collected at one tributary station during stormflow. Deionized water was used to prepare a field blank for each parameter at one tributary station during baseflow. Samples were stored on ice and delivered to the laboratory within 24 hours after collection. Figure 2.2 shows the location of the tributary sites.

2.4.2 BIOLOGICAL INFORMATION

The Division of Nature Preserves, Indiana Department of Natural Resources was contacted to identify significant natural areas and state-listed species found in the vicinity of Big Lake and its watershed. In addition, visual reconnaissance, aerial photographs, and other available maps were used to identify important wetland complexes located in the Big Lake watershed.

SECTION 3. WATERSHED SOILS AND LAND USE

Watershed soils and land use are primary factors in determining the water quality status of lakes. A detailed account of the soil associations and land use follows.

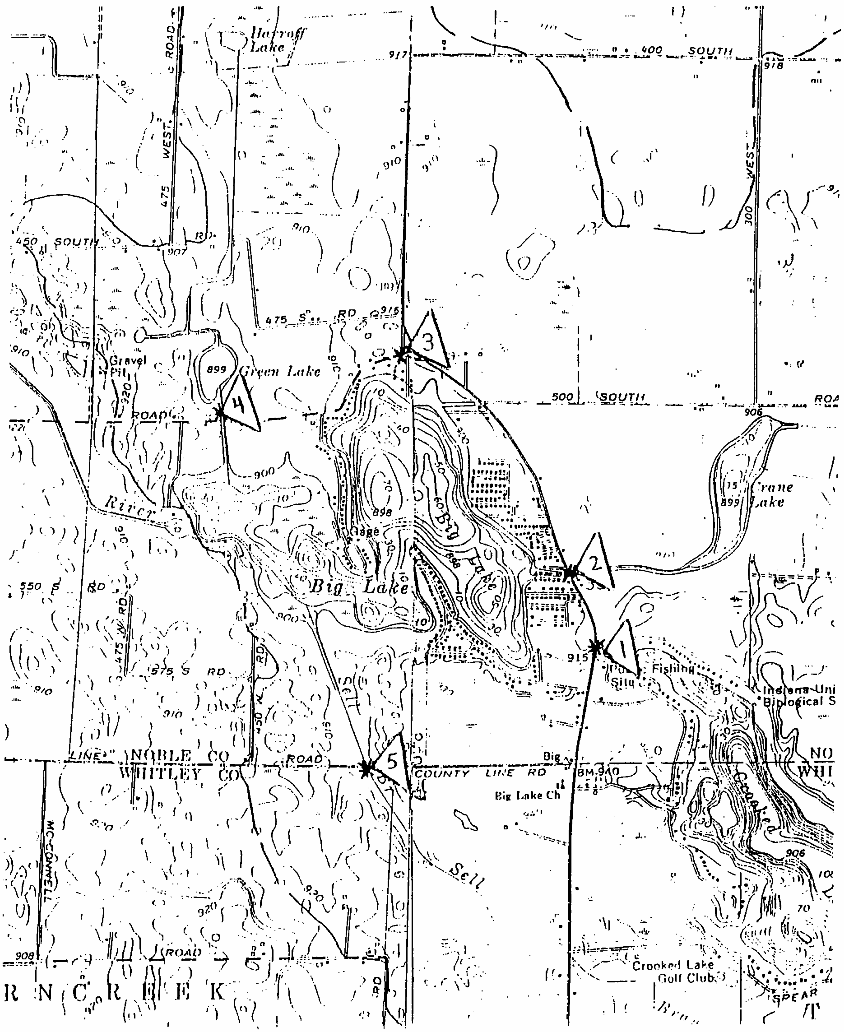
3.1 SOILS AND LIMITATIONS

The Big Lake watershed lies in both Whitley and Noble Counties. The following report is a summary of the general soils association descriptions from the Noble and Whitley County Soil Surveys.

A soil association is a landscape that has a distinctive proportional pattern of soils. It normally includes one or more major soils and at least one minor soil and is named for the major soil(s). Soil associations do not fully agree with the association in adjoining counties but commonly match according to parent material or some major and minor soils.

The soils of Noble and Whitley Counties formed in glacial till, sand and gravel outwash, alluvium deposits, and organic deposits. Soils that formed in till are well drained to very poorly drained and are medium or moderately fine textured. Soils that formed in outwash are medium or

Figure 2.2. Map of sampling sites on each of five tributaries to Big Lake in Noble and Whitley counties.



moderately coarse textured and are very poorly drained to excessively drained. Alluvial soils on floodplains are medium textured and somewhat poorly drained. Organic soils consist of muck and peat and are very poorly drained. Soil types and associations are listed in Table 3.1. The percentage of the Big Lake watershed area that consists of each soil association is given in Table 3.2.

Table 3.1. Soil types found within the soil associations for each county in the Big Lake watershed.

Noble County

Morley-Blount Association	Haskins-Toledo Association	Houghton-Edwards Association
Minor soils	Minor soils	Minor soils
Pewamo	Fulton	Palms
Washtenaw	Rawson	Wallkill
Rawson	Milford	Sebewa
Haskins		
Shoals		

Whitley County

Morley-Rawson Association	Morley-Glynwood Association
Minor soils	Minor soils
Blount	Blount
Coesse	Hennepin
Glynwood	Houghton
Haskins	Martisco
Muskego	Pewamo
Pewamo	Rawson
Seward	Seward

References: Noble County and Whitley County Soil Survey

Table 3.2. Soil associations as percentage of the Big Lake watershed in Noble and Whitley Counties.

Type	Percentage of Watershed
Morley-Blount	33%
Houghton-Edwards-Adrian	23
Haskins-Toledo	22
Morley-Glynwood	19
Morley-Rawson	3
Total	100%

3.1.1 NOBLE COUNTY SOILS

The soils in the Noble County portion of the watershed consist of three soil associations:

Morley-Blount Association

The southern edge of the county extending through Crooked Lake subwatershed and into the northeast side of Crane Lake subwatershed is the Morley-Blount association. These soils are well drained to somewhat poorly drained, nearly level to moderately sloping, deep soils that have a fine and moderately fine textured sub-soil on uplands. Erosion is a hazard on Morley soils. Wetness is a limitation on Blount soil. When considering residential and commercial developments, erosion can be a problem on sloping terrain. If soil erosion is controlled, these soils are productive cropland, woods, and wildlife habitat.

Haskins-Toledo Association

These soils are somewhat poorly and very poorly drained nearly level, deep soils that have moderately fine or fine textured sub-soil on outwash plains and uplands. These soils extend from the extreme western side of Big Lake across State Road 109 into the western side of Crane Lake subwatershed. These soils are also found in the northeast portion of the Green Lake subwatershed. This association is nearly level and is normally not erosive. Wetness is a severe limitation when considering commercial and residential developments. These soils are generally considered good for agricultural crops and wildlife, as well as woodland on well drained sites.

Houghton-Edwards-Adrian Association

These soils are very poorly drained, nearly level mucks that are deep or moderately deep over marl or sand and gravel in depressions on uplands and outwash plains. The areas included in the association are the southern edge of Big Lake extending northeast including Crane Lake and the area north of Crane Lake. Also included is an area one-quarter mile north of Big Lake including most of Stuckman Branch subwatershed and the northeastern portion of Green Lake subwatershed. Wind erosion is a hazard. Wetness is severe and drainage is necessary on crop land. Houghton soils are a source of marl. This association is not recommended for any residential or commercial developments because of wetness and high organic content. Without drainage these soils are not considered good for agricultural row cropping or woodland. They are good for wetland restoration.

3.1.2 WHITLEY COUNTY SOILS

The soils in the Whitley County portion of the watershed consist of two soil associations:

Morley-Rawson Association

These soils are mainly level to steep, well drained and moderately well drained soils formed in glacial till and loamy outwash over glacial till on till plains and moraines. These soils are found in the extreme northwest corner of the Sell Branch subwatershed. Erosion is a problem on sloping land. Wetness is also a problem, especially in depressions where impounding occurs. These soils provide good support for woodland and wildlife habitat. Development for residential and commercial uses is not recommended because of slopes and wetness. Agricultural production of crops is generally good, if soil erosion is controlled.

Morley-Glynwood Association

These soils are gently sloping to steep, well drained and moderately well drained soils formed in glacial till on plains and moraines. These soils are included in the remainder of the Sell Branch subwatershed. Erosion is a major hazard. If land is used for cultivated crops, erosion control measures are needed. Wetness is also a problem, especially in low areas where ponding occurs. Residential and commercial developments are not recommended due to slope and wetness. These soils are productive for woodland, wildlife, and agricultural crops when managed properly.

3.2 LAND USE

The Big Lake watershed is typical of most lake watersheds in Northern Indiana. Agriculture is the dominant land use, heavy development has occurred around the lake, and artificial drainage has allowed for more farming and development.

Soil erosion is costly for rural and urban citizens. Erosion diminishes productivity and increases runoff by reducing infiltration, basic plant nutrients, and degrades soil structure. Conventional, plow-disk farming of corn in Indiana induces soil loss of 47 tons per ha. As a result, corn yields on severely eroded soil have been shown to decrease by up to 24 percent on Illinois and Indiana farms. Erosion rates of 17 tons/ha/yr (6.9 tons per acre) could cost farmers $196/ha/yr ($79 per acre) to replace the benefits of water and nutrients (Pimentel and others 1995). For every $1 invested in soil conservation, an estimated $5.24 in replacement costs would be saved.

One of the long-term costs of erosion is deteriorating water quality. About 60 percent of the tons of soil lost from U.S. cropland each year is deposited in streams and rivers (USDA 1989). This sediment clogs waterways and reduces the storage capacity of reservoirs. Dredging to remove silt and restore function to these systems cost over $520 million annually in the United States (Clark 1985).

Three criteria are used to determine if a soil is highly erodible: 1) soil textures or make-up; 2) rainfall; and 3) length and degree of slope. The Big Lake watershed has 1,558 acres of highly erodible soils draining into the lake. Figure 3.1 shows the location of highly erodible soils (HEL) in the watershed. Highly erodible areas require management practices that maximize soil retention. Appropriate farming practices are particularly important where HEL areas intersect with agricultural use (Figure 3.2). In the last 20 years, conservation tillage and the Conservation Reserve Program (CRP) reduce erosion and runoff in areas farmed by row cropping.

The Sell Branch subwatershed contains the largest acreage of highly erodible soils. However, less than half of these acres are being used intensively for agricultural row crops. Many of the highly erodible soils are in grassland and forested use.

The Crane Lake subwatershed has the second highest number of acres of highly erodible soils. Nearly two-thirds of the area in HEL is being used intensively for agricultural row crops. Most of the highly erodible land in this subwatershed is above Crane Lake, such that Crane Lake could be serve as a critical sediment and nutrient trap. The remaining subwatersheds have a smaller amounts of highly erodible soil.

Several problems were obvious in the watershed. Stream bank erosion was prevalent in some areas and could be greatly reduced by simply stabilizing banks after ditch maintenance. Allowing filter strips of grasses and legumes or trees around fields would slow runoff and filter sediment and nutrients before they enter streams leading to the lake.

Many problems in the watershed could be solved using existing state and federal programs that promote conservation. Working to develop a good relationship with the residents of the watershed and lake will assist in promoting conservation practices in the region. Further details on soils and land use are given below for each subwatershed.

Figure 3.1. Map of highly erodible land (HEL) in the Big Lake watershed in Noble and Whitley counties.

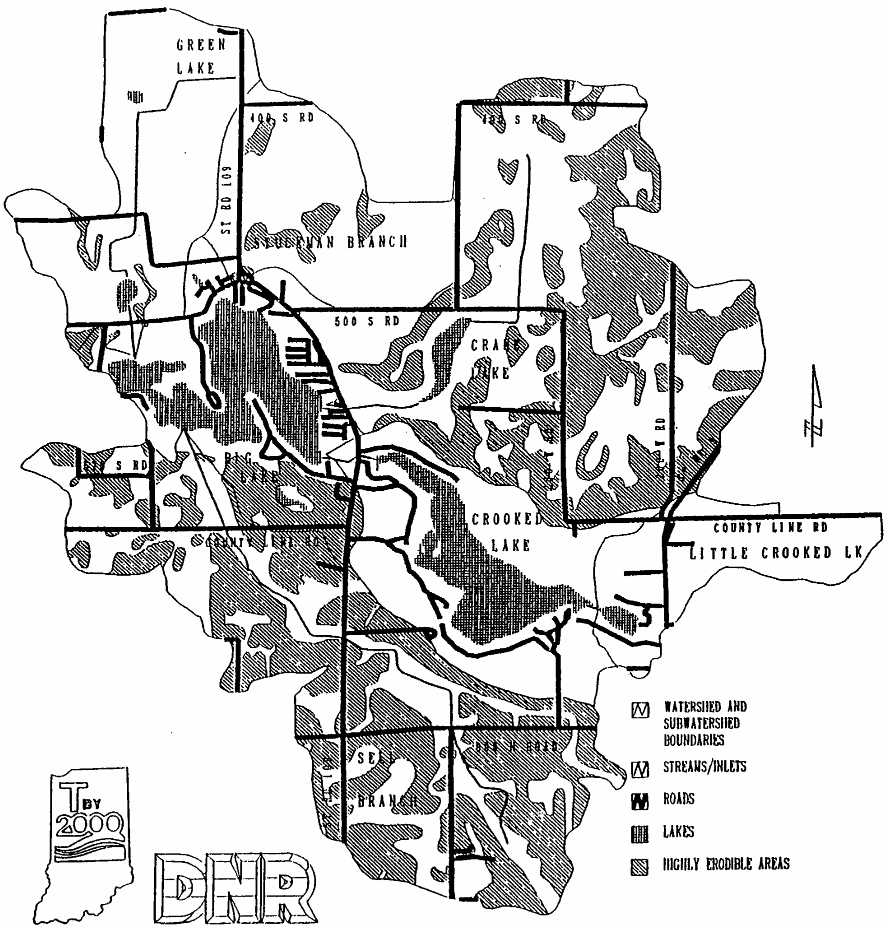
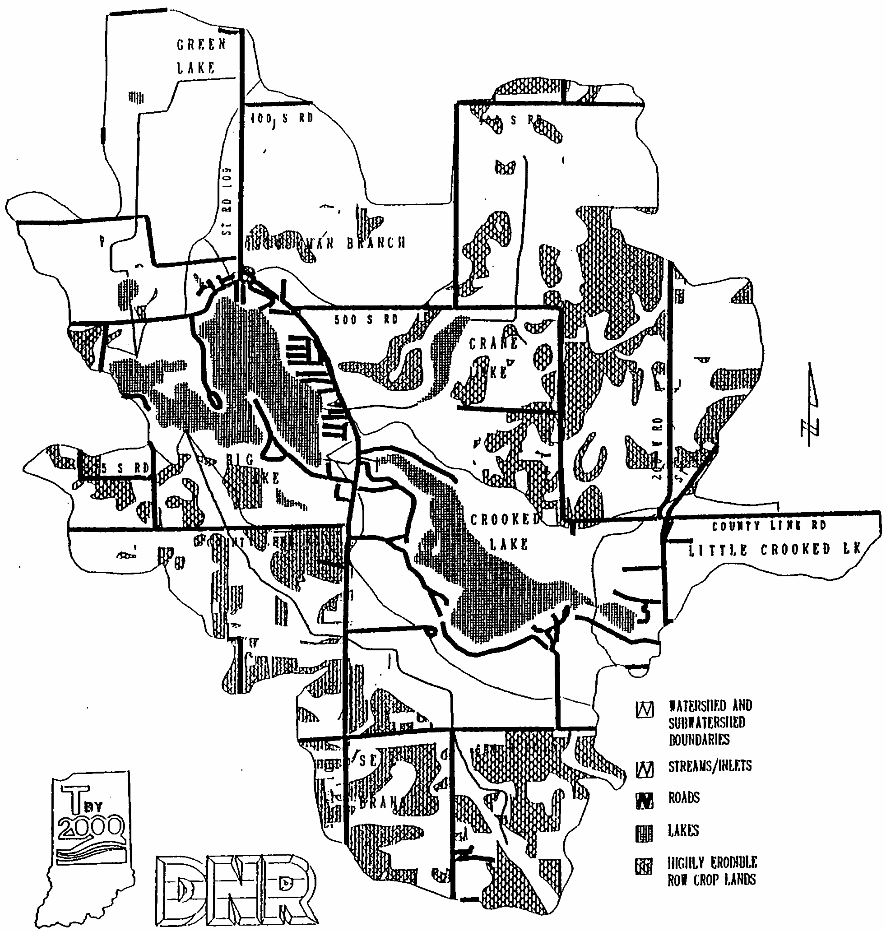


Figure 3.2. Map of crop land over highly erodible land (HEL) in the Big Lake watershed in Noble and Whitley counties.



3.2.1 HISTORICAL LAND USE AND TILLAGE TRENDS

On December 11, 1816, Indiana was admitted into the Union as a state. Its northern portion was then an almost unbroken wilderness, of which little was known, except that it abounded in wild game and was the home of several groups of Native Americans. The first settler to appear in the Noble County area was Joel Bristol, who arrived in April of 1827. In 1836, less than 100 settlers were in the area and Noble County was organized (History of Northeast Indiana, 1920).

The first agricultural crops grown by the settlers were corn, potatoes, turnips, and wheat. Clearing of the land had to be done before any crops could be grown. Much of the area was covered by swamps. Disease was a constant threat.

During the early 1900s, there were over 2,962 farms in Noble County totaling 264,765 acres. Several different crops were being grown at that time including corn, rye, oats, barley, buckwheat, alfalfa, timothy hay, potatoes, onions, apples, peaches, and pears. Also, several thousand head of livestock were pastured (History of Northeast Indiana, 1920).

Tillage of the soil was originally done using a moldboard plow. Farming methods continued to be the same until the past few decades, when conservation tillage methods were introduced and farms changed from grain and livestock to primarily grain. Conservation tillage is any of several methods that leave at least 30 percent of the previous year's crop. In the past decade, conservation tillage methods have become adopted by more and more farmers (Table 3.3).

Table 3.3. Trends of conservation tillage on full season corn and soybean crops in the years 1984 and 1991.

Total planted (acres)		Conservation tillage (acres)		Conservation tillage (percent)	
1984	1991	1984	1991	1984	1991
230,200	220,764	60,341	102,738	26%	46.5%

Data for Whitley and Noble Counties, Indiana. Provided by Conservation Tillage Information Center, West Lafayette, IN.

Land use in the Big Lake watershed has changed in recent years in relation to habitat for rare species of plants (Table 3.4). Crooked Lake drains into Big Lake and is bordered by a large nature preserve area with a number of threatened and endangered species. Natural areas around Crooked Lake could act as a source for recolonization of protected habitats around Big Lake. The largest protected region in the immediate area of Big Lake was Long Swamp Woods Natural Area, which was a forested wetland in private ownership around Harroff Lake in the Green Lake subwatershed.

Table 3.4. Occurrence of protected species in the region around Big Lake and Crooked Lake. Date of most recent collection and status at that time is given. (SX=state extirpated; SE=state endangered; ST=state threatened; SR=state rare; SSC=species of special concern for animals; WL=watch list for plants)

Common name	Scientific name	date	status
Crooked Lake subwatershed			
Cisco	Coregonus artedii	1990	SSC
White stem pondweed	Potamogeton praelongus	1985	ST
Fries' pondweed	Potamogeton friesii	1962	SE
Flatleaf pondweed	Potamogeton rabbinsii	1962	SE
Straightleaf pondweed	Potamogeton strictifolius	1962	SE
Horsetail spikerush	Eleocharis equisetoides	1982	SE
Shining ladies-tresses	Spiranthes lucida	1987	ST
Lesser bladder wort	Utricularia minor	1982	SE
Loesel's twayblade	Liparis laeselii	1982	WL
Purple-fringed orchis	Platanthera psychodes	1955	SR
Pale green orchis	Platanthera flava	1949	SR
Illinois hawthorn	Crataegus prona	1935	SE
Big Lake and Green Lake subwatersheds			
Cisco	Coregonus artedii	1955	SSC
Three-awn grass	Aristida intermedia	1945	ST
Wild calla	Calla palustris	1900	SE
Tamarack	Larix laricina	1968	WL
Mountain holly	Nemopanthus mucronata	1968	SR
Goldthread	Coptis trifolia	1968	WL

Forested areas also dramatically affect the hydrology and water quality of an area by increasing infiltration and evapotranspiration of water and slows the runoff of soil and water. Over the past 30 years, the amount of forested land in the watershed has dropped by half from 900 acres in 1963 (IDNR 1964) to 451 acres in 1992, which most likely increases erosion and runoff rates.

At the same time, residential use of Big Lake has grown. The number of residential homes around the lake increased by 40 percent from 326 lakeside homes in 1963 to 461 in 1991. Most residential development occurred in the

1950s and 1960s. By 1974, fifty percent of the shoreline was developed (IDNR 1975).

3.2.2 CURRENT LAND USE AND EROSION POTENTIAL

Water quality in Big Lake is influenced by land use activities in the areas draining into the lake. The watershed for Big Lake is 5,009 acres in size. Agriculture is the dominant land use at 72.5 percent of total area. The remainder of the area is in forest, wetlands, open water, idle land, and residential use (Figure 3.3).

The dominant land use differed in the five subwatersheds: Sell Branch, Crane Lake, Green Lake, Stuckman, and the immediate area around Big Lake (Figure 3.4). More detailed information on land use is given below for each subwatershed, based on data collected in 1992.

Big Lake subwatershed

The Big Lake subwatershed consists of the area around the lake which drains directly into the lake. The total acreage is 648 acres, of which 90 acres are potentially highly erodible.

The Big Lake subwatershed had 116 acres of agricultural row crops within the area. Twenty-nine acres were considered to be highly erodible. Most of the row crop land was on the southwest side of the lake. Most of the potentially erodible area which was currently in row crops was away from the lake and did not pose an immediate threat to the lake.

Grassland made up five percent (30 acres) of the area. Twenty-nine of the acres were considered to be highly erodible. Most of the grassland was in the Conservation Reserve Program (CRP). The CRP program was part of the 1985 Farm Bill. The program allowed landowners to bid their land into the program and receive an annual rental payment for up to ten years, if the land was planted to grasses and legumes, and up to 15 years, if trees were planted. Established vegetation provided a permanent cover for the soil and minimizes erosion. There were no problems found in this land use that would negatively affect the lake. Maintaining the land in grasses would be important for minimizing soil erosion.

Forested land made up three percent (22 acres) of the subwatershed. None of the forests were on potentially highly erodible soils. The southern shore of the lake was where most of the forested land was located. This area was important to the lake by providing fish habitat, water filtration, and wildlife habitat.

Figure 3.3. Map of land use in Big Lake watershed in Noble and Whitley counties.

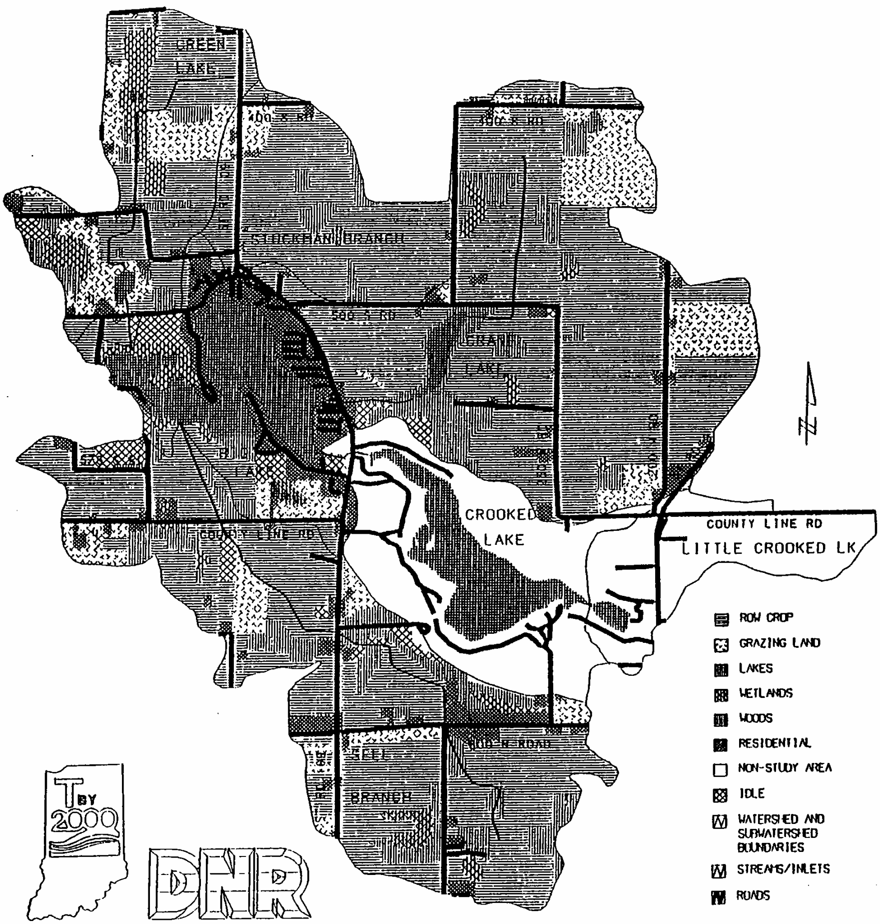
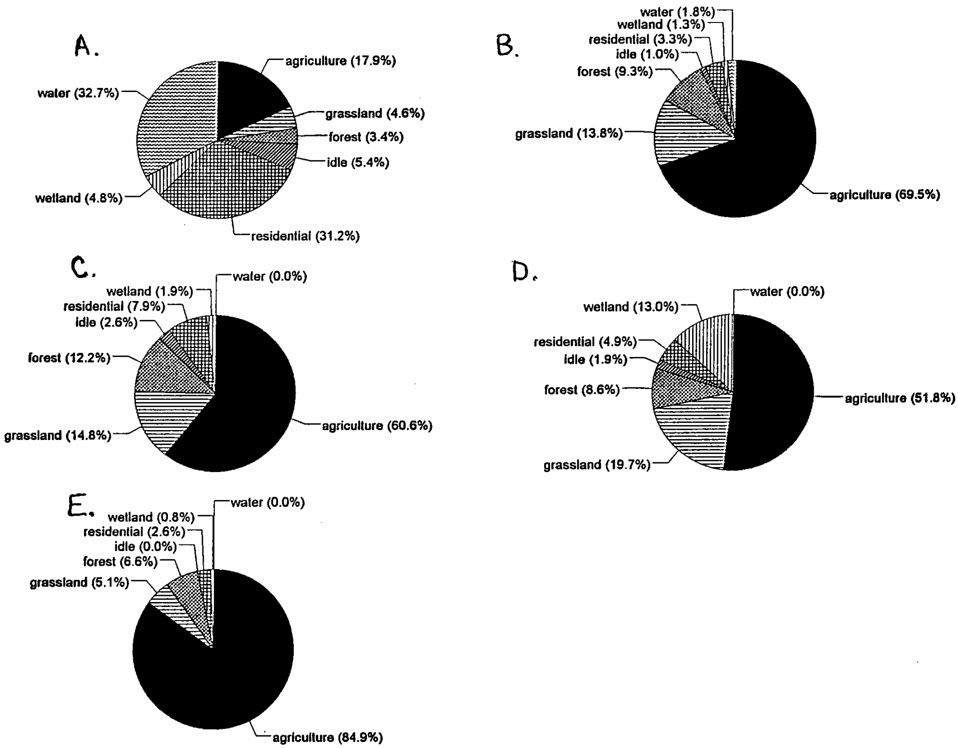


Figure 3.4. Land use in five subwatersheds of Big Lake watershed in Noble and Whitley counties: a) Big Lake; b) Crane Lake; c) Sell Branch; d) Green Lake; and e) Stuckman Branch.



Idle land made up five percent (35 acres), eight acres of which were potentially highly erodible. Most of this land was located on the north and west sides of the lake. As long as the vegetative cover is not disturbed, this area should not negatively affect the lake.

Residential land constituted 31 percent of the area, 24 acres of which were potentially highly erodible. Development in the immediate vicinity of the lake was very heavy. Negative impacts of development were likely to stem from use of on-site sewage disposal systems.

Wetland areas made up five percent (35 acres), most of which was along the lake shore. Protection of wetlands would be recommended for filtration of nutrients and sediment and habitat for fish and wildlife.

Big Lake itself made up the remainder of the subwatershed at 33 percent (228 acres).

Crane Lake Subwatershed

The Crane Lake subwatershed had an area of 1,681 acres. Of this area, 652 acres were considered to be highly erodible.

Seventy percent (1,168 acres) of this watershed was in agricultural row crops. Potentially highly erodible soils made up 37 percent (432 acres) of this land use. The Crane Lake subwatershed had the largest amount of highly erodible soils in row crops for the entire Big Lake watershed. There were several areas where gullies could be clearly seen in fields, particularly in areas south and west of Crane Lake.

The 1957 aerial photographs showed that the area along the east side of County Road 250 West was forest. Since then, the area had been converted to row crops, and erosion was a severe problem. The roadside ditches along County Road 250 West were full of sediment and required frequent maintenance. Several other areas in this subwatershed had been farmed so intensively that the roadside ditch was no longer discernable and corn rows were found within a few feet of the roadside.

There were two main ditches that drain into Crane Lake, entering from the north and from the southwest. Both ditches had areas where streambank erosion was visible. In this case, streambank erosion was caused by water flow in the ditch cutting at the ditch bank, which resulted in caving in of the steep banks. In some areas, the last row of corn or soybeans was at the edge of the ditch bank. This also can cause erosion and caving in when equipment is used near the bank and runoff can flow directly over the bank.

Figure 3.5 shows areas along the ditch where soils were susceptible to erosion and caving banks.

Grassland made up 14 percent (232 acres) of this subwatershed, 129 acres of which were potentially highly erodible. Most of this land was farmed in row crops according to 1957 aerial photographs. Since then, approximately 171 acres of this land had been removed from production and enrolled in CRP.

Forested land made up nine percent (156 acres), 48 acres of which were potentially highly erodible. The amount of erosion in forested areas was very minimal. Conversion of this land to row crops would produce a potential erosion and water quality problem.

Idle land consisted of only one percent (17 acres) of the subwatershed, 10 acres of which were potentially highly erodible. Residential areas are not normally considered to be contributors to water quality problems, unless excessive lawn fertilizers and pesticides are used or septic systems are leaching into ground and surface waters. During the land use inventory, there was no visible evidence of problems from residential areas in this subwatershed.

Wetland areas made up one percent (22 acres) of the subwatershed. Much of the area north of Crane Lake had soil types which indicated that much of the area was once wetland. The Clean Water Act and 1985/1990 Farm Bills recognized the values of wetlands and regulated further drainage of wetlands.

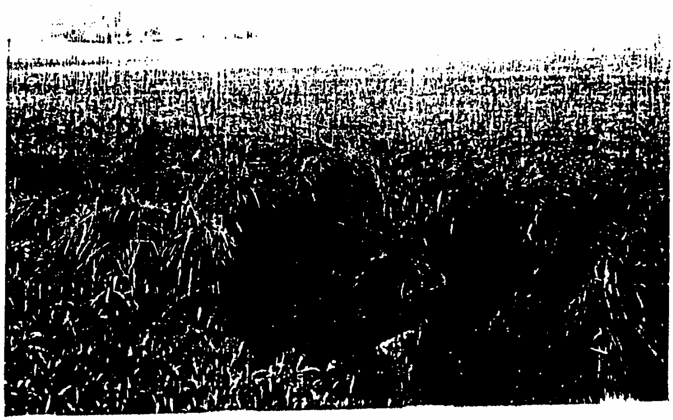
Open water made up the remainder of the Crane Lake subwatershed at two percent (30 acres). Crane Lake was the main body of water in the subwatershed and was located about one-half mile east of Big Lake. Crane Lake served as a sediment and nutrient trap for this subwatershed.

Sell Branch Subwatershed

The Sell Branch subwatershed had an area of 1,510 acres, 754 of which were considered to be potentially highly erodible land.

Agricultural row crops constituted 60 percent (915 acres) of the subwatershed. Potentially highly erodible soils made up 40 percent (3,667 acres) of this land use. The Sell Branch subwatershed had the second largest amount of potentially highly erodible land in the study area. Most of the row cropland was farmed using minimum till methods, in which some of the previous year's crop residue was left on the surface after planting (NRCS-Whitley County). This method of farming helps to control soil erosion. The 1957 aerial photographs showed that small fields of 10-20 acres

Figure 3.5. Ditch banks in the Big Lake watershed that show signs of instability through erosion and caving in.



were most common, indicating more crops in rotation. As of 1992, most of the field were larger and had rotations of only corn and soybeans.

The Sell Branch was the only drainage ditch in this subwatershed. There were several underground tiles that drain areas in this subwatershed. The Sell Branch ditch had areas where streambank erosion was a problem. The cause of erosion was water undercutting banks and causing caving-in of banks. There were several areas where row crops were too close to the ditch bank, which also can cause caving in when water washes down the bank.

Grassland made up 15 percent (224 acres) of this subwatershed. Potentially 162 acres of this land was highly erodible. There were approximately 200 acres of this land use in the CRP program. The 1957 aerial photographs showed most of this land was used for agricultural row crops in the past. Since enrollment in CRP, grasses and legume cover may have reduced erosion rates in this area.

Forested land constituted of 12 percent (184 acres) of this subwatershed. Potentially 125 acres were highly erodible. The amount of forested land had not changed significantly since 1957. Conversion of this land to row crops would create a potential erosion and water quality problem.

Idle land consisted of only three percent (39 acres) of this subwatershed, 14 acres of which were potentially highly erodible. Unless this land is disturbed for farming or urban development, negative impacts from this land will be minimal.

Residential land made up eight percent (119 acres) of the subwatershed, 86 acres of which were potentially highly erodible. Significant problems due to sediment or nutrient runoff and septic system leaching were not observed in this area.

Wetland areas made up two percent (29 acres). This land use was in two areas, the wooded area west of Airport Road and another area north of C.R. 600 North and west of Spear Road.

This subwatershed was one of two that had concentrations of livestock in 1992. One farm did not appear to be in operation at the time of this study, but had an earthen animal waste pit. The other farm was a working dairy farm. Animal waste management could affect water quality. For instance, leaking animal waste pits and manure spread on frozen ground can run off into nearby streams and increase nutrient levels in the lake.

Green Lake Subwatershed

The Green Lake subwatershed had an area of 639 acres, of which 13 acres were considered to be potentially highly erodible. This subwatershed was relatively flat and had the highest percentage of wetlands in comparison to the other subwatersheds.

Fifty-one percent (326 acres) of this watershed was in agricultural row crops with five acres identified as potentially highly erodible. This was the lowest amount of highly erodible soils of any subwatershed in the study area. Only one potential problem area could be identified during the study. The row crop field southeast of Green Lake and on the north side of C.R. 500S sloped down to the ditch. The potential existed for sediment and nutrients to enter the ditch from this field.

All of the drainageways in this subwatershed flowed into one ditch on the north side of Green Lake. They continued as one ditch as Green Lake drained into Big Lake. Streambank erosion could have been a problem on any of these ditches.

Grassland made up 19 percent (124 acres) of the subwatershed, of which five acres were potentially highly erodible. Hay crops was grown on some of this land. Hay crops are normally rotated with grain crops. Because the amount of potentially highly erodible land was small, this type of crop rotation should not create undue amounts of erosion.

Forested land covered eight percent (54 acres) of this subwatershed. According to 1957 aerial photographs, forested land formerly covered several more acres east of Harroff Lake, but by 1992, the land was in agricultural production. Protecting the remainder of the forested land would be recommended.

Twelve acres of the subwatershed lay idle. None of these acres were considered to be highly erodible.

Residential land constituted five percent (31 acres) in the area. Most of this land use consisted of farmsteads scattered around the subwatershed which did not appear to pose problems for the lake.

Wetland areas covered 13 percent (82 acres) of this area. Most of the wetland acreage was around Harroff Lake. Green Lake was located so that it acted as a sediment and nutrient trap for the subwatershed.

Stuckman Branch Subwatershed

The Stuckman Branch subwatershed was the smallest of the subwatersheds in this study. Only 531 acres drained into Stuckman Branch.

Agricultural row crops made up 85 percent (451 acres) of this subwatershed, 24 acres of which were potentially highly erodible. Due to the low amount of potentially highly erodible soils, erosion did not appear to present a major problem.

The Stuckman Ditch was the main waterway in this subwatershed.

Grassland made up five percent (27 acres) of the area. Nine acres of this were considered to be potentially highly erodible. Most of this land use was located in the northern part of the subwatershed along S.R. 109. None of this land appeared to be causing erosion problems for the lake.

Forested land constituted seven percent (35 acres). Fifteen of these acres were considered to be potentially highly erodible. Protection of these remaining forests was recommended to prevent disturbance of erodible soils.

There was currently no idle land in this subwatershed.

Residential land made up two percent (14 acres) of this subwatershed. Most of the residential land consisted of small farmsteads scattered throughout the area. There was a heavier concentration of residences where Stuckman Branch flowed into the lake. Septic systems may have been a contributor of nutrients to the lake.

Wetlands made up one percent (4 acres) of this subwatershed. All four acres were located in a wooded area east of S.R. 109 and north of C.R. 500S. Soil types found within this subwatershed indicated that wetlands were probably once a much larger portion of this area.

Section 4.0 WATER QUALITY IN BIG LAKE AND TRIBUTARIES

Water quality can limit the types or extent to which the lake provides resources in the form of drinking water supplies, recreational body contact in swimming and boating, fishing, and wildlife habitat. A combination of physical and chemical factors interact to create the water quality conditions found in a particular lake. The following section compares data taken during this study to historical data from the watershed, where available.

4.1 LAKE WATER QUALITY

Lakes are complex ecosystems in which physical, chemical, and biological characteristics function interdependently. Large scale factors, such as climate and geology, set the boundaries within which lake characteristics develop. Some physical and chemical factors, like temperature and light, determine the type of organisms that can survive in the system. Other physical and chemical factors, like dissolved oxygen, may indicate biological activity. Physical, chemical, and biological characteristics of Big Lake are outlined below.

4.1.1 STRATIFICATION

At the beginning of the summer, deep lakes in northern Indiana will stratify with warmer water near the top and colder water near the bottom. Many physical, chemical, and biological characteristics of the lake are controlled by stratification. Under these circumstances, water in the epilimnion (upper portion) does not mix readily with water from the hypolimnion (lower portion). Deeper portions of the lake may become oxygen depleted in eutrophic, or aging, lakes as organic matter decomposes. Lower levels of oxygen may preclude habitatation by fish in cooler parts of the lake and cause release of phosphorus and toxic substances due to chemical reactions in deoxygenated bottom sediments.

Temperature data were only available for 1992 and showed distinct thermal stratification (Figure 4.1). In 1990, the metalimnion separated the upper and lower portions of the lake where temperature changed most rapidly at depths between 12 and 18 feet. Lake temperature dropped from 72 degrees F at the surface to 46 degrees F at the bottom during late summer stratification.

Dissolved oxygen data taken during five years since 1963 in Big Lake showed a changing pattern of stratification (Figure 4.2). Dissolved oxygen varied with no particular temporal pattern between 7.5 mg/L in 1963 and 12 mg/L in 1974. In all years, dissolved oxygen dropped precipitously to nearly zero at depths of 12 to 25 feet. Oxygen levels below 4 mg/L are generally too low for most aquatic organisms. Therefore, only the upper 12 feet provided habitat for most animal species in the lake during the summer.

In the three most recent years (1987, 1990, 1992), the dissolved oxygen curve was positively heterograde, increasing to 2-6 mg/L at around 40 feet (12.2m). Heterograde curves are generally a result of oxygen production from bluegreen algae or macrophytes (larger plants) growing below the thermocline. This possibility is discussed in more detail below.

Figure 4.1. Stratification of temperature and dissolved oxygen at the deepest point of Big Lake in Noble county on 25 June 1992.

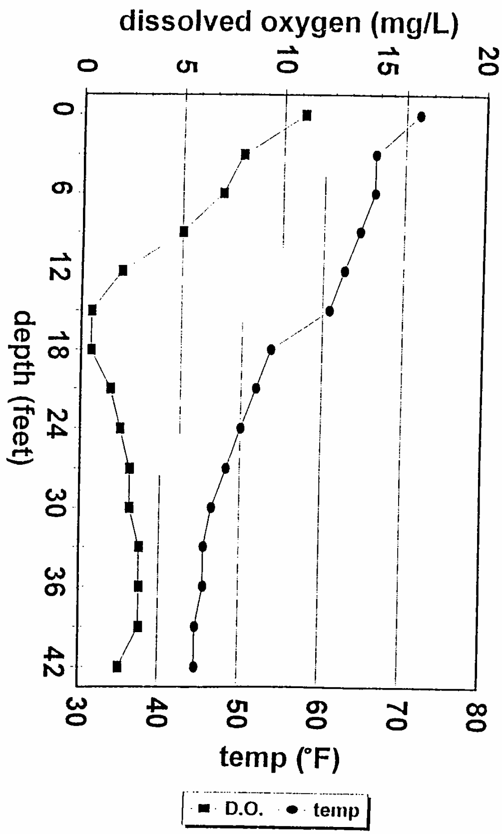
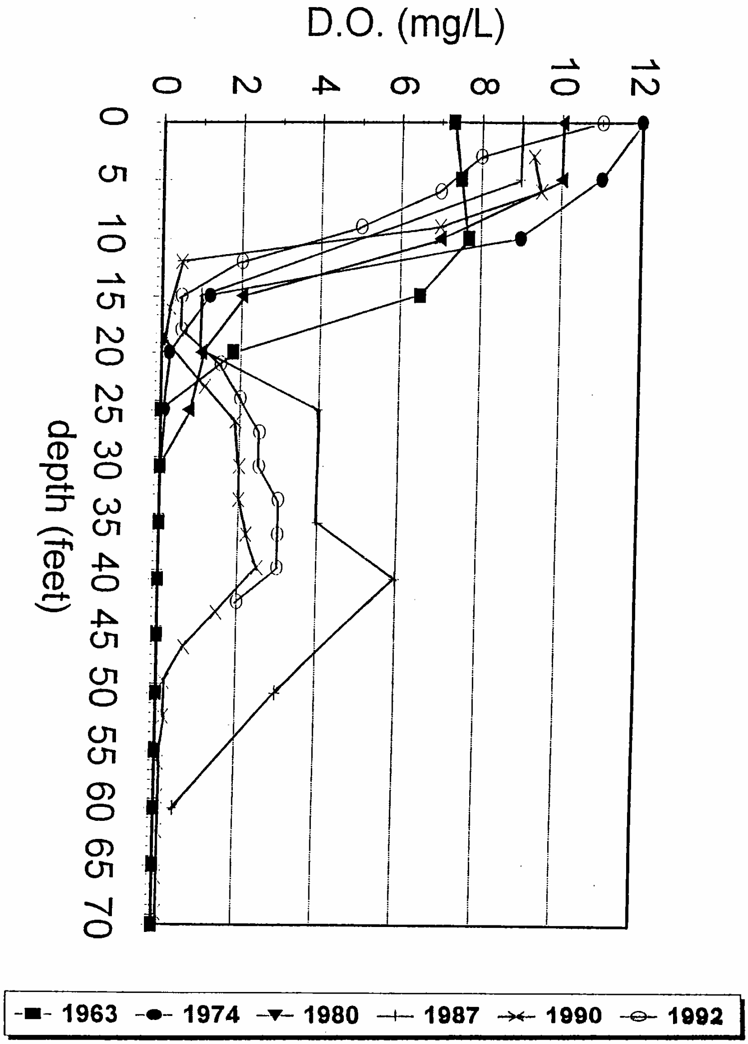


Figure 4.2. Stratification of oxygen levels at the deepest point of Big Lake in Noble county from six years (1963-1992).



Acidic and basic properties of the lake affect the chemical state of many important compounds in the water. Acidity causes release of toxic heavy metals, such as mercury and aluminum. Ammonia toxicity increases in basic water. Highly productive water tends to have high pH levels during the day and low levels at night in response to photosynthesis by plants. The pH levels in Big Lake were typical for northern Indiana lakes, ranging from 7.2 to 8.5 in the epilimnion and from 7.1 to 7.5 in the hypolimnion over four years of study from 1974 to 1992 (Table 4.1).

However, pH level at the surface was approximately one pH unit lower in 1974 compared to 1990, 1991, and 1992. This difference in basicity represents a multiple of 10, because pH is on a logarithmic scale, and may be due to increasing photosynthesis in the lake.

Table 4.1. Levels of pH at the surface and deepest point in Big Lake during four years of study (1974-1990, IDEM; 1992, IDNR).

depth	year 1974	1990	1991	1992
epilimnion	7.2	8.4	8.0	8.5
hypolimnion	7.2	7.1	7.3	7.5

Alkalinity indicates the buffering capacity of water and is important in resisting pH changes. High alkalinity will reduce radical swings in pH due to high photosynthesis and will moderate effects of acid precipitation. Alkalinity in Big Lake during three years of study (1974 and 1990) was typical of marl lakes in northern Indiana (Figure 4.3). Alkalinity levels indicated high buffering capacity. Alkalinity was not measured in 1992.

Photosynthetic precipitation of calcium carbonate in marl lakes can diminish total alkalinity, especially in combination with rising temperatures, which reduces the solubility of calcium carbonate. For this reason, alkalinity is generally lower at the surface than at the bottom of productive lakes, including Big Lake, during the summer. Surface alkalinity increased from 1963 to 1990, indicating a possible drop in photosynthetic productivity or an increase in sources of alkalinity, which could include phosphate pollution or sedimentation. Alkalinity was also higher in the hypolimnion of Crane Lake in 1991 than in any year measured in Big Lake, possibly because Crane Lake acts as a sediment and nutrient detention basin for Big Lake (Table 4.2).

Figure 4.3. Alkalinity in Big Lake at the surface and deepest point during three years of study (1963, 1974, 1990, IDEM).

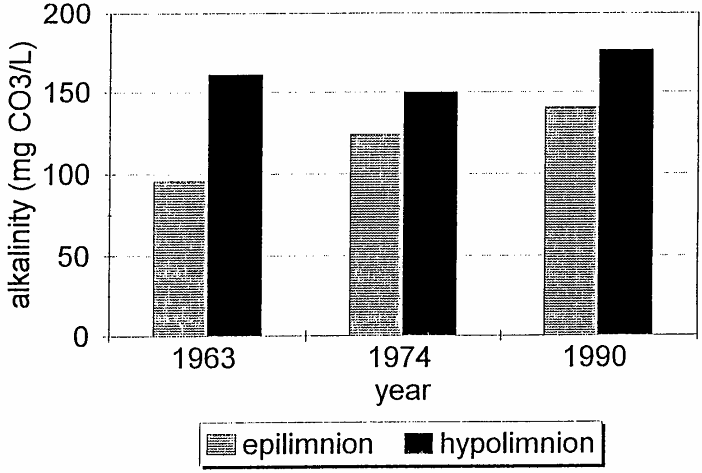


Table 4.2. Alkalinity (mg CO3/L) at the surface and deepest point in Big Lake during three years of study (1963, IDEM; 1974, IDEM; 1990, IDEM) and at the deepest point in Crane Lake during one year (1991, IDEM).

level:	epilimnion				hypolimnion			
year:	1963	1974	1991	1990	1963	1974	1991	1990
Big Lake	96	124	--	140	161	150	--	176
Crane Lake	--	146	--	--	--	272	--	--

4.1.2 LIGHT AND PHYTOPLANKTON

Phytoplankton are microscopic plants that function as the primary producers of food and oxygen in lake ecosystems. As with other plants, phytoplankton require light to thrive. Transparency and light penetration in the water regulate the type and location of phytoplankton in the lake. In turn, phytoplankton often control dissolved oxygen levels in eutrophic lakes.

Water clarity in Big Lake appeared to cycle between "good" and "poor" in measurements taken during nine of 30 years since 1963 (Figure 4.4). High water clarity was somewhat associated with lower rainfall, possibly as a result of drier conditions resulting in less runoff, less erosion, and lower turbidity. According to a scale used by the Wisconsin Department of Natural Resources (Rumery, 1987), Secchi disk readings below five feet indicate "poor clarity," which would include readings from Big Lake in half of the years surveyed since 1974.

Big Lake periodically attains water clarity nearly equal to that of other lakes in the same region (Table 4.3). In 1993, Secchi disk readings averaged 8.2 feet in lakes from Noble and Whitley County and 6.5 feet in 39 lakes across northern Indiana. On the Wisconsin DNR scale, these average Secchi disk readings are between 6.5 and 10 feet, which would indicate "good clarity." However, Big Lake may have a potential for better than average water clarity. In 1993, nearby Crooked Lake had an average summer reading of 15.4 feet, nearly twice that of Big Lake at 7.7 feet.

Figure 4.4. Summer Secchi disk readings in Big Lake in Noble county from nine years (1963-1994). Data from 1992-1994 are given as July/August averages.

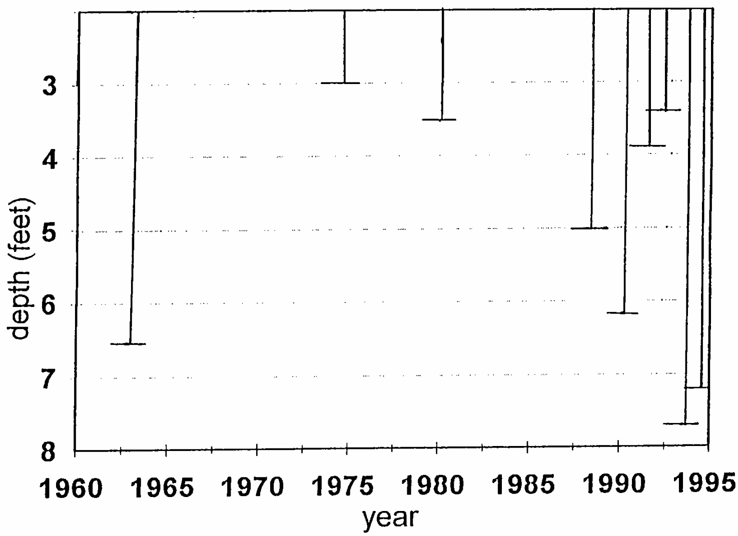


Table 4.3. Mean Secchi disk readings during July and August, 1993, at eight lakes in Noble and Whitley Counties.

Lake	County	Maximum (feet)	Minimum (feet)	Mean (feet)
Bear	Noble	10.3	4.8	5.4
Big Cedar	Whitley	16.0	12.0	10.3
Big	Noble	12.0	3.5	7.7
Crooked	Noble	15.8	11.3	15.4
Goose	Whitley	12.0	5.0	9.7
High	Noble	12.5	2.5	2.8
Little Long	Noble	9.0	4.0	5.8
Long	Noble	9.8	4.5	8.4
AVERAGE		12.2	6.0	8.2

The photic zone, or portion of the water column with light sufficient for photosynthesis and plant growth, extends to a depth where only one percent of surface light remains. Measurements of light transmission paralleled Secchi disk readings in Big Lake. At a depth of 3 feet, light levels were reduced to only 14 percent in 1992, but remained at approximately 37 percent of surface light in 1990. In most eutrophic lakes, oxygen levels do not increase below the photic zone. As a rule of thumb, the photic zone extends to about 3.0 times the Secchi disk depth. This relationship suggests that beneficial algae and green plants could grow to depths of 9 to 23 feet in Big Lake, depending upon the year.

In highly eutrophic lakes, turbidity increases during the spring runoff, followed by a proliferation of planktonic algae through the summer months, both of which can limit growth of rooted aquatic plants. Decreases in water clarity due to sediment runoff should be more apparent in the spring, during a period of high rainfall, as was seen in 1992. In contrast, light levels have been decreasing later in the summer during 1993 and 1994, suggesting that water clarity was more likely related to growth of planktonic algae.

The majority of the phytoplankton species found in Big Lake in 1990 and 1992 consisted of the bluegreens *Aphanizomenon*, *Anabaena*, *Oscillatoria*, and *Microcystis*, as well as the dinoflagellate *Ceratium* and the diatoms *Fragilaria* and *Asterionella* (Table 4.4; IDEM, 1990). These species are very common constituents of hardwater lakes and are all representative of eutrophic conditions. The diatom *Asterionella* is especially known from lakes in watersheds where agricultural runoff and erosion occur; *Fragilaria* is common in lakes which receive sewage inputs (Williams, 1969).

Table 4.4. Plankton collected from a station at the deepest point of Big Lake in two years (1990, IDEM; 1992, IDNR).

Species	epilimnion and metalimnion 7/2/90 #/L	%	epilimnion only 6/25/92 #/L	%
Cyanophyta (bluegreen algae)	1,181,741	99%	520,917	98%
Anabaena	1,943		3,361	
Aphanizomenon	1,172,000		516,116	
Coelosphaerium	9			
Gomphosphaeria	18			
Oscillatoria	7,771			
Microcystis			1,440	
Chlorophyta (green algae)	3,886	0.3	480	0.09
Sphaerocystis			480	
Ulothrix	3,886			
Chrysophyta (diatoms)	1,942	0.2	0	0.0
Dinobryon	971			
Mallamonas	971			
Pyrrophyta (dinoflagellates)	1,943	0.2	9,602	1.8
Ceratium	1,943		9,602	
Chrysophyta (diatoms)	3,885	0.3	480	0.09
Asterionella	971		480	
Fragilaria	1943			
Synedra	971			
TOTAL	1,193,745	100%	532,039	100%
Other organisms:				
Zooplankton	348	0.03	---	
Ployartha	106			
Cyclopoid	63			
Daphnia	21			
Nauplii	158			

Bluegreen algae create a nuisance in lakes used by humans. These species cause noxious blooms and high daytime pH levels in eutrophic lakes (Prescott, 1982). Although these algae may produce high levels of oxygen during the day, respiration at night and decomposition of large dying populations can consume even more oxygen.

Bluegreen algae are capable of producing energy at lower light levels than most green algae and are better competitors than green algae under eutrophic conditions. Green algae provide vital energy to the ecosystem through primary production. In contrast, few aquatic organisms can feed on bluegreen algae. Three of the genera of bluegreens found in this lake have been implicated in the poisoning deaths of fish and domesticated animals in a few other lakes (Cole, 1983).

In the three most recent years (1987, 1990, 1992), the dissolved oxygen curve was positively heterograde, increasing to 2-6 mg/L well below the photic zone at around 40 feet. This trend indicated the possible existence of certain types of bluegreen algae, such as Oscillatoria, which are uniquely capable of inhabiting very dimly lit deeper waters. Oxygen produced by these bluegreens can become trapped below the thermocline during stratification. The oxygen released by these bluegreens is not likely to enhance habitat for other aquatic organisms due to reduction in oxygen with respiration at night.

The increase in oxygen was greatest in 1987 and seemed to be diminishing somewhat since then. Phytoplankton data corroborate this pattern. Oscillatoria was the second most common constituent of the phytoplankton in 1990 at 7,771/L. In 1992, Oscillatoria was not specifically identified in the collection. The most likely reasons that the species was not collected in 1992 include: 1) the plankton tow did not include the deeper metalimnion layer in which Oscillatoria was probably located; and 2) net mesh size was smaller in the tow net used in 1990 than in the net used in 1992 (Kelly Boatman, Division of Soil Conservation, IDNR, pers. comm., May 23, 1995).

In either case, Oscillatoria seems to have decreased in concert with a recent lack of oxygen in deeper parts of the lake. Unfortunately, phytoplankton samples have not been retrieved recently from deeper zones (around 40 feet) where Oscillatoria was probably most common in 1987.

Populations of Oscillatoria may increase in deeper lake zones as a result of nitrogen limitation (Cole, 1983). The apparent population explosion around 1987 may indicate a large increase in phosphorus influx relative to nitrogen. More recent decreases in deep lake oxygen levels suggest decreasing phosphorus levels or increasing nitrogen.

4.1.3 MACROPHYTES

Diversity of native vascular plant communities in Big Lake has diminished significantly over the past 30 years (Table 4.5). Between 1963 and 1980, the number of plant species collected from the lake dropped by over 40 percent from 17 to 10. Not until 1992 did the number of species improve by addition of four species not previously known from the lake. Five species have never recovered, including bass weed (Potomogeton amplifolius) and four other related species.

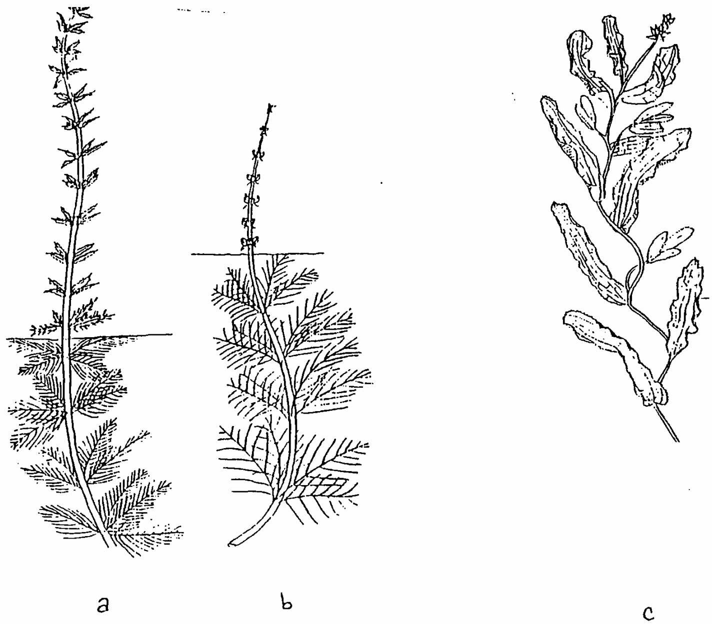
Table 4.5. Aquatic plants collected from Big Lake (1963-1992).

Common name	Scientific name	1963	1980	1987	1992
Bass weed	Potomogeton amplifolius	X			
Bushy pondweed	Najas flexilis	X	X		
Cattail	Typha latifolia	X	X	X	X
Chara	Characeae chara	X	X	X	X
Coontail	Ceratophyllum demersum	X	X	X	X
Curly-leafed pondweed	P. crispus			X	X
Duckweed	Lemna spp.				X
Elodea	Anacharis canadensis	X			X
Floating-leaf pondweed	P. zosteriformis	X			
Illinois pondweed	P. illinoensis	X			
Leafy pondweed	P. foliosus	X			
Narrow-leafed pondweed	Potomogeton spp.				X
Sago pondweed	Potomogeton pectinatus	X		X	
Sedges	Eleocharis spp.				X
Smartweed	Polygonum spp.				X
Spatterdock	Nuphar advena	X	X	X	X
Swamp loosestrife	Decodon verticillatus				X
Three-square bulrush	Scirpus americanus	X	X	X	
Water bulrush	Scirpus subterminalis	X	X	X	X
Water lily	Nymphaea odorata	X	X	X	X
Water milfoil	Myriophyllum spp.	X	X	X	X
Wild celery	Vallisneria americana	X	X	X	
Total number of native species		17	10	10	13
Total number of exotic species		0	0	2	2

Native aquatic plant species found in Big Lake most likely provided important habitat for fish and other animals. In Texas, survey data from 30 reservoirs revealed a strong positive relationship between submerged plants and largemouth bass recruitment and population size (Durocher et al., 1984). Flowering aquatic plants enhance the aesthetic appearance of the lake and provide food for waterfowl, muskrats, and other wildlife. Fish feed on aquatic insects that thrive on submerged and floating plants.

Populations of two species of exotic water plants appear to be increasing--Eurasian watermilfoil and curly-leafed pondweed (Figure 4.5). Both plants form tangled surface mats of vegetation that interfere with recreational use of lakes. Large masses of dying plant material can

Figure 4.5. Illustrations of two exotic plant species that occur in Big Lake: (a) Eurasian water milfoil and (c) curly-leafed pondweed. (b) shows native milfoil for comparison.



decompose, absorbing oxygen and creating an unsightly nuisance. Few native species of fish and wildlife are accustomed to using exotic plants for food or shelter. Floating exotics can shade out beneficial native species of plants.

The extent of exotic species of plants in the lake appeared to be somewhat limited at the time of the study. Species lists for 18 sections of the shoreline indicated greater dominance of these exotic species near the more residential areas along the eastern portion of the lake (Table 4.6, Figure 4.6).

4.1.4 FISH

Big Lake originally supported a relatively diverse fish community, apparently lost several species over a period of time from the end of the 19th Century and into the early 1970s, but may have stabilized over the past 20 years at a lower level of diversity (Table 4.7).

Species that apparently disappeared from the lake prior to 1974 included black bullhead, bluntnose minnow, longnose gar, spotted sucker, and blackstripe topminnow. According to Pfleiger (1975), many of these species thrive in clear water and/or require extensive aquatic vegetation. Several of these species have specific requirements for spawning habitat. Blackstripe topminnow are found along the shoreline in emergent aquatic vegetation. Bluntnose minnow deposit eggs on the flat undersurface of objects over sand or gravel. Black bullhead spawn under large objects and are more tolerant of turbid water. Declines in these species may reflect decreased cover in the form of aquatic vegetation and submerged woody debris or increased turbidity, depending upon species requirements.

Table 4.6. Aquatic plant species found in sampling zones.

Area	Common Name	Scientific Name	Comments
1	Yellow water lily	Nuphar advena	Dense growth; dominant
	Cattail	Typha latifolia	Near shore
	Curly-leafed pondweed	Potamogeton crispus	Extending to 10-12 ft.
	Water milfoil	Myriophyllum spp.	Extending to 10-12 ft.
2	Cattail	Typha latifolia	Near shore
	Bulrush	Scirpus spp.	Near shore
	Curly-leaved pondweed	Potamogeton crispus	Sparse
	Water milfoil	Myriophyllum	Dominant
3	Cattail	Typha latifolia	On either side of inlet
	Curly-leafed pondweed	Potamogeton crispus	Moderate growth
	Water milfoil	Myriophyllum spp.	Moderate growth
	Elodea	Elodea canadensis	
	Arrow Arum	Peltandra virginica	
	Bulrush	Scirpus spp.	
	Chara	Characeae chara	
	Narrow-leafed pondweed	Potamageton spp.	
	Water Bulrush	Scirpus subterminalus	Near shore on point
	Duckweed	Lemna spp.	
4	Water milfoil	Myriophyllum spp.	Dominant
	Curly-leafed pondweed	Putamogeton crispus	Subdominant
	Yellow water lily	Nuphar advena	Small patch
	Cattail	Typha latifolia	Near shore east of inlet
	White Water Lily	Nuphar odorata	On northern tip of area
	Filamentous algae		Large mat in northern tip
5	Water milfoil	Myriophyllum spp.	Dominant; but sparse
	Curly-leafed pondweed	Potamogeton crispus	Sparse; wave action
	Yellow water lily	Nuphar advena	Small patch
	Filamentous Algae		Small mat
6	Water milfoil	Myriophyllum spp.	
	Cattail	Typha latifolia	
	Filamentous Algae		In the channel
7	Cattail	Typha latifolia	
	Water milfoil	Myriophyllum spp.	
	Bulrush	Scirpus spp.	
	Filamentous algae		Left of the channel
8	Cattail	Typha latifolia	On the point and bay
	Water milfoil	Myriophyllum spp.	Growth not excessive
	Curly-leafed pondweed	Potamogeton crispus	Growth not excessive
	White water lily	Nuphar odorata	Near channel opening
	Swamp loosestrife	Decodon verticillatus	Sparse
	Yellow water lily	Nuphar advena	Abundant in the bay

Table 4.6. Aquatic plant species continued.

9	White water lily Curly-leafed pondweed Water milfoil	Nuphar odorata Potamogeton crispus Myriophyllum spp.	
10	Cattail White water lily Curly-leafed pondweed Yellow water lily	Typha latifolia Nuphar odorata Potamogeton crispus Nuphar advena	Patchy
11	Water milfoil Curly-leafed pondweed White water lily Filamentous algae Sedges	Myriophyllum spp. Potamogeton crispus Nuphar odorata Eleocharis spp.	Dense growth
12	Cattail Yellow water lily Swamp loosestrife Smartweed	Typha latifolia Nuphar advena Decodon verticillatus Polygonum spp.	
13	Yellow water lily Curly-leafed pondweed Water milfoil Cattail White water lily	Nuphar advena Potamogeton crispus Myriophyllum spp. Typha latifolia Nuphar odorata	
14	Cattail Curly-leafed pondweed Water milfoil Spatterdock White water lily Swamp loosestrife	Typha latifolia Potamogeton crispus Myriophyllum spp. Nuphar spp. Nuphar odorata Decodon verticillatus	
15	Curly-leafed pondweed Water milfoil	Potamogeton crispus Myriophyllum spp.	
16	Cattail Water milfoil Curly-leafed pondweed Spatterdock Coontail Narrow-leafed pondweed filamentous algae	Typha latifolia Myriophyllum spp. Potamogeton crispus Nuphar spp. Ceratophyllum demersum Potamogeton spp.	
17	Water milfoil Curly-leafed pondweed	Myriophyllum spp. Potamogeton crispus	Dominant
18	--	--	Vegetation-none

Figure 4.6. Map of aquatic plant sampling zones from Big Lake, Noble County, on 14 June 1992. Table 4.3 gives listings of species and density in each zone.

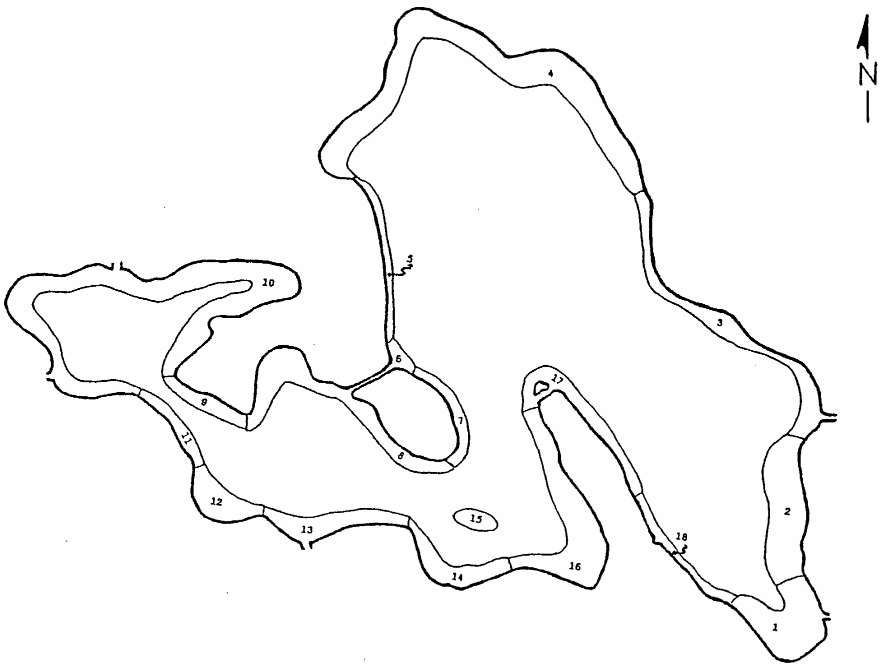


Table 4.7. Fish species collected from Big Lake (1894-1987).

Species	1894	1963	1974	1980	1987
Black bullhead		X			
Black crappie		X		X	X
Blackstripe topminnow	X				
Bluegill	X	X	X	X	X
Bluntnose minnow	X				
Bowfin		X		X	X
Brook silverside				X	
Brown bullhead	X			X	
Carp		X		X	
Channel catfish					X
Cisco	X				
Golden shiner		X	X	X	X
Grass pickerel	X	X	X	X	X
Green sunfish		X		X	
Lake chubsucker		X	X	X	X
Largemouth bass	X	X	X	X	X
Log perch			X		
Longnose gar	X	X			
Pumpkinseed		X		X	X
Redear sunfish		X	X	X	X
Spotted gar		X	X	X	X
Spotted sucker		X			
Warmouth	X	X	X	X	X
White sucker		X		X	X
Yellow bullhead		X	X	X	X
Yellow perch	X	X	X	X	X
TOTAL SPECIES	10	19	12	18	16

Like several other lakes in the region, cisco, Coregonus artedi, once inhabited Big Lake, but have not been collected since 1894. Cisco is a fish species that requires well-oxygenated, cold water and so has a predominantly northern distribution. The southernmost populations of cisco lived in northern Indiana lakes, until nutrient and sediment influx decreased the preferred habitat of this species in many lakes. Cisco populations in several Indiana lakes were formerly large enough to sustain a commercial fishery, but were common in only six lakes as of 1993 (Koza, 1995).

Exotic species can contribute to deteriorating habitat and water quality in lake ecosystems. At high densities, carp may increase turbidity by stirring bottom sediments. Carp were present in the lake, but not abundant. The zebra mussel, Dreissena polymorpha, is an exotic species which interferes with human use of aquatic systems by fouling objects and organisms in lakes and rivers. As of February, 1995, these exotic mussels were known to have spread to only three lakes in Indiana (Tippecanoe Lake, Lake Wawasee, and Syracuse Lake), all in Kosciusko County. These three lakes are located less than 15 miles from Big Lake. At the time of this study, no exotic mussels had been reported from Big Lake.

In comparison to the situation in Indiana, a total of 25 Michigan inland lakes had displayed some evidence of zebra mussel infestation by November, 1994, with 14 lakes having confirmed adult mussel populations (Michigan DNR, 1995). All but one of the 25 lakes exhibiting evidence of zebra mussel infestation have public access sites. Boating habits of lakefront residents may also be a primary factor in the spread of exotic mussels. These small mussels can be transferred between waterways through attachment to boats, buckets, and other equipment.

All studies since 1963 report that gamefish populations have consistently been in good condition. Bluegill growth and condition rank average or above average for area lakes. Fish surveys over the past 30 years indicated that largemouth bass were abundant, but small or thin (Pearson, 1987; Pearson, 1980; McGinty, 1966). Other gamefish, such as perch, crappie, and panfish, inhabit the lake and could support greater interest from anglers.

4.1.5 NUTRIENTS AND TROPHIC STATUS

Productivity in lakes is largely determined by relative amounts of phosphorus and nitrogen. Other nutrients are usually present in sufficient quantities and are less important in regulating populations. Depending upon the species, algae generally require a ratio of total nitrogen to total phosphorus of 15:1 (U.S. EPA, 1980). Ratios of 10:1 or less indicate nitrogen limitation. Ratios of 20:1 or more suggest phosphorus limitation. Physical and chemical parameters indicate the level of productivity (eutrophication) in the lake. The range of levels that indicate productivity are given in Appendix I.

Nitrogen

The nutrient analysis for Big Lake is typical of a very eutrophic stratified lake in summer. Organic (total Kjeldahl) nitrogen levels nearly tripled from 0.57 mg/L in the epilimnion and hypolimnion in 1974 to around 1.7 mg/L in 1990 (Figure 4.7). Organic nitrogen then stabilized in the epilimnion, but continued to increase in the hypolimnion to 2.7 mg/L in 1992. Ammonia levels show a very similar pattern, increasing in the hypolimnion by a multiple of seven between 1974 and 1992 to nearly 1.39 mg/L (Figure 4.8).

Figure 4.7. Total Kjeldahl nitrogen concentrations in the epilimnion and hypolimnion of Big Lake, Noble County, in three years (1974, 1990, 1992).

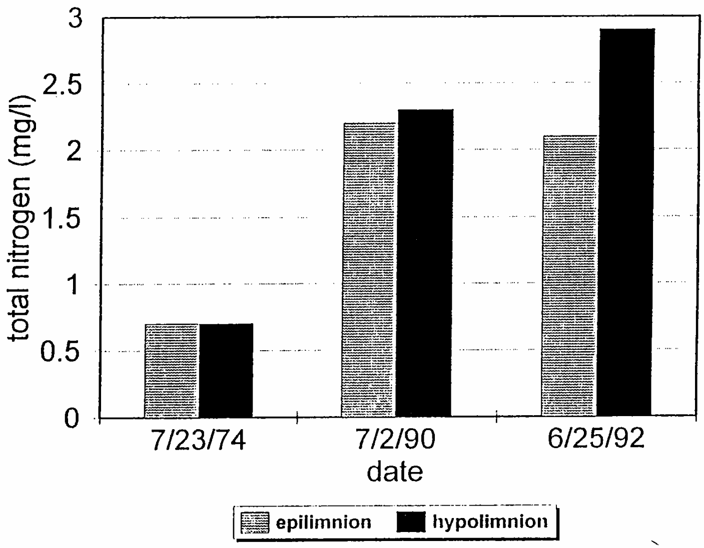
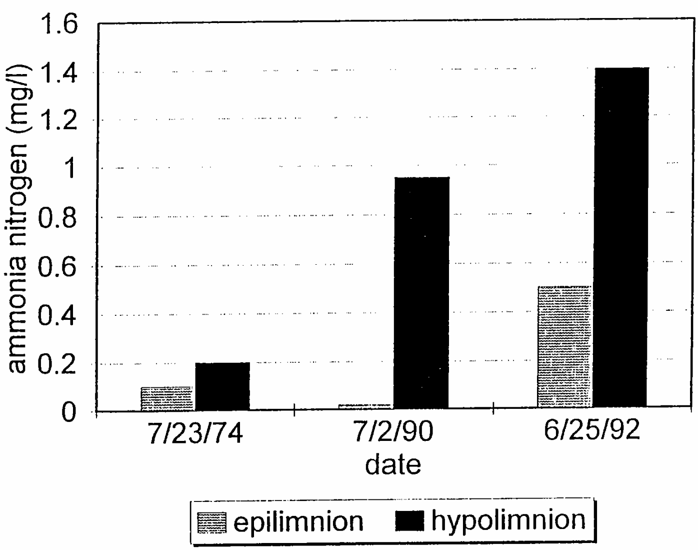


Figure 4.8. Ammonia nitrogen concentrations in the epilimnion and hypolimnion of Big Lake, Noble County, in three years (1974, 1990, 1992).



Although ammonia is a form of nitrogen that plants can readily use for growth, at high concentrations, it is poisonous to fish and other animals, including humans. Ammonia levels of 0.5-4.6 mg/L killed 50 percent of bluegill within 96 hours in laboratory tests (Roseboom and Richey, 1977). Other species native to Indiana show similar intolerance to high ammonia levels. If ammonia levels increase much beyond the present state or if summer storms caused lake turnover in Big Lake, fish kills could result.

The pH of water dramatically affects the toxicity of ammonia. At a pH of 9.0, it takes 100 times less total ammonia to kill the same number of fish as compared to a pH level of 6.5 (Thurston et al., 1981). Most lakes in northern Indiana have high pH levels, which will multiply the toxic effects of ammonia. In addition, photosynthesis of large quantities of plants or algae during the day can drive up pH levels and increase the toxicity of ammonia in productive lakes. As indicated above, the pH of Big Lake was typical for a northern Indiana lake, but daytime pH appeared to be becoming more basic over time, perhaps due to increasing photosynthesis.

Low levels of nitrogen may be limiting for beneficial green algae and diatoms. However, bluegreen algae are generally capable of fixing nitrogen from atmospheric sources. Aphanizomenon was much more common than Anabaena in Big Lake (Table 4.4) and is less efficient at fixing nitrogen (Horne, 1979). Therefore, control of nitrogen supplies in Big Lake could be effective in reducing populations of the most common bluegreen algae in the lake.

Sources of nitrogen in lakes are varied, diffuse, and extremely difficult to control. Major natural sources of organic nitrogen and ammonia in the hypolimnion are excretion and decay of dead organisms. As stated above, bluegreen algae can remove nitrogen from the air and fix it for use by aquatic plants. Artificial sources of nitrogen and ammonia include fertilizers in agricultural runoff and lawn chemicals, as well as sewage inflows.

Phosphorus

Phosphorus acts as the limiting agent for biological productivity in most lake systems. Both green and bluegreen algae are dependent upon phosphorus present in the water for growth. Levels of total phosphorus above 20-30 ug/L indicate eutrophication in temperate North American lakes (U.S. EPA, 1980). Because sources of phosphorus are fewer and more easily controlled than nitrogen, most lake restoration efforts focus on this nutrient.

Phosphorus loading may be from external or internal sources. Agricultural runoff and human waste from sewage outfalls contribute phosphorus from the watershed. Because phosphorus readily attaches to soil particles, sedimentation can bring phosphorus into the lake where it becomes concentrated in lake sediments of the hypolimnion. Under low oxygen or high pH conditions, phosphorus is released back into the water in the stream or from sediments the lake. During summer storms or spring and fall turnover, phosphorus in the hypolimnion can be transported to the epilimnion, where it can cause periodic algal blooms.

Overall, the level of phosphorus in Big Lake has increased by a multiple of four in the past 20 years. However, the largest portion of phosphorus in the lake has shifted from 80 percent of total stores in surface water (epilimnion) in 1974 to 74 percent in deep water (hypolimnion) by 1992 (Figure 4.9). Between 1974 and 1990, phosphorus levels in surface water (epilimnion) dropped dramatically, then increased in 1992 and appear to be stabilizing or dropping since 1992. It is important to note that these data were from samples taken on one summer day in each year of study. Total phosphorus levels in Big Lake have fluctuated by as much as 45 ug/L during summer months in three recent years of study (1992-1994; Figure 4.10).

The overall ratio of total nitrogen to total phosphorus has fluctuated widely in the three years for which data are available. In 1974 and again in 1992, the ratios of 8:1 and 4:1 indicate nitrogen limitation and an abundance of phosphorus. Between these years, data from 1990 showed a high level of phosphorus limitation and an overabundance of nitrogen with a ratio of 62:1.

Chlorophyll-a

Most of the phosphorus in the water column at Big Lake was probably incorporated into planktonic algae, which in turn was apparently largely responsible for decreases in water clarity in some years (Figure 4.10). Chlorophyll-a is a measure of the amount of planktonic algae in the water. Seasonal patterns in total phosphorus were closely related to chlorophyll-a levels and Secchi disk reading during the summers of 1992 and 1993. However, the relationship was not as apparent in 1994, when the level of phosphorus was unusually high, water clarity was fairly good, and chlorophyll-a was unusually low throughout the summer.

Both phosphorus and chlorophyll-a levels can be used to indicate the degree of eutrophication in the lake. In all three years, the level of phosphorus matched or exceeded the 20-30 ug/L limit that indicates eutrophication according criteria set by US EPA (1980). In 1992 and 1993, the mean and maximum levels for chlorophyll-a met or exceeded the US

Figure 4.9. Total phosphorus concentrations in the epilimnion and hypolimnion of Big Lake, Noble County, in five years (1974, 1990, 1992-1994). Data from 1993 and 1994 are given as July/August averages from the epilimnion.

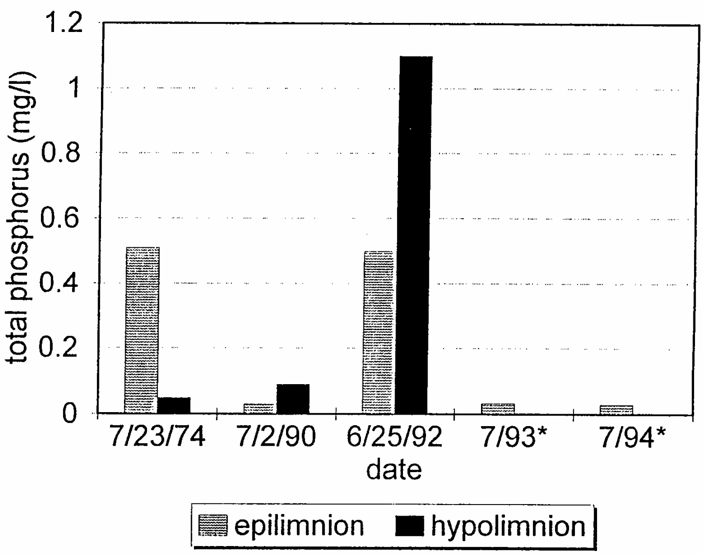
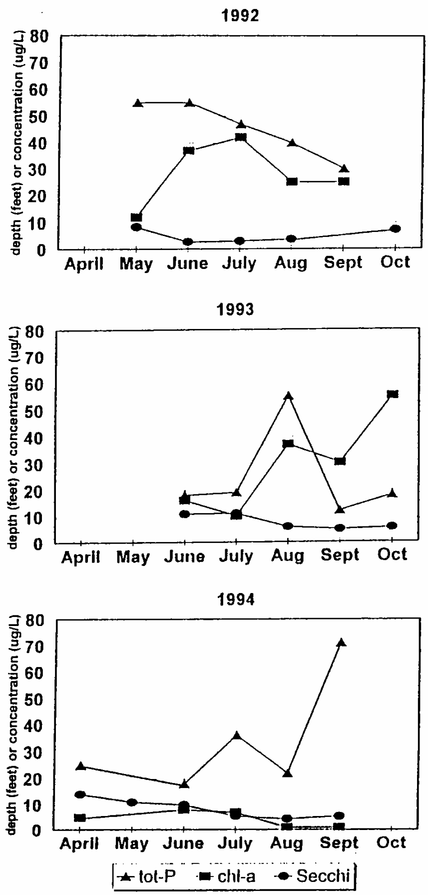


Figure 4.10. Monthly averages for total phosphorus, chlorophyll-a, and Secchi disk readings during April to October of 1992-1994.



EPA (1980) criteria of 6-10 ug/L for eutrophication. However, chlorophyll-a levels were relatively low in 1994 and entered but did not exceed the critical range during May through July of that year.

Trophic classifications

Several methods exist for determining the trophic status, or degree of eutrophication, in lakes. The Indiana Department of Environmental Management (IDEM) has developed an index which ranges from 0 to 75 by assigning eutrophy points for a variety of parameters. The classification system based on total points is as follows:

Class I - highest quality, least eutrophic lakes (0-25)
Class II - intermediate quality and eutrophy (26-50)
Class III - lowest quality, advanced eutrophy (51-75)
Class IV - remnant natural lakes and oxbow lakes

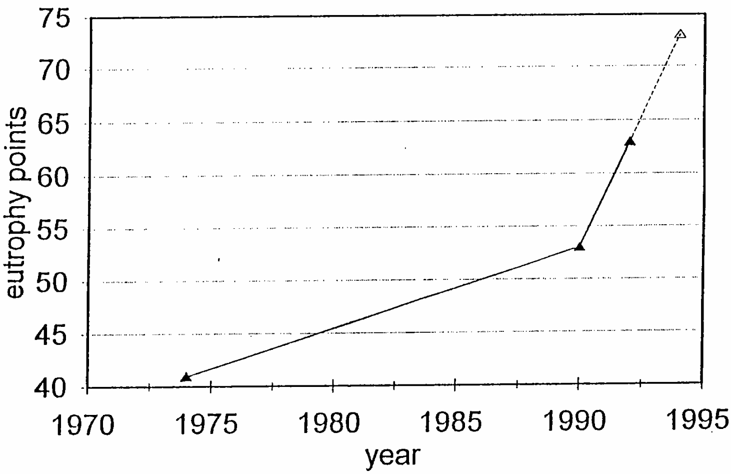
Values used in the calculation of the Eutrophication Index also indicate general ranges for various parameters that would indicate the level of productivity in a lake. The ranges used for calculating a Eutrophication Index are given in Appendix I.

According to this system, the quality of Big Lake steadily deteriorated over the 1970s and 1980s and is currently degrading at a much higher rate. Since 1974, Big Lake has deteriorated from Class II "intermediate" (38 points) to Class III "lowest quality" with 64 out of 75 possible points in 1992 (Figure 4.11). Through the 1970s and 1980s, the lake gained an average of one point per year but gained 10 points in two years between 1990 and 1992. At the current rate of increase, the lake would degrade below the Class III category by 1995.

However, some uncertainty exists in the data, because the scores were determined for only one set of data. Indices are generally designed to account for natural variability by assigning score for a range of values. Values that lie on the breakpoint between scores are most significant in altering the index.

Trophic indices can also be used to identify the most serious problems and set goals for increasing water quality in lakes. Parameters contributing most to declining water quality on the IDEM scale were related to soluble phosphorus, light penetration, and high populations of bluegreen phytoplankton (Table 4.8). To drop out of the U.S. EPA criteria for eutrophication, summer total phosphorus at the surface of Big Lake would have to be reduced by one-third to one-half of current levels (below 0.2-0.3 mg/L) and Secchi disk clarity would have to double to at least 5-6.5 feet (U.S. EPA 1980). Only parameters

Figure 4.11. Eutrophication scores (IDEM scale) for Big Lake, Noble County, in three years (1974, 1990, 1992). Value for 1994 is estimated, based on increases between 1990 and 1992.



related to dissolved oxygen have improved since 1974 (Table 4.9).

Table 4.8. IDEM Eutrophic Index values for Big Lake, 25 June 1992. Calculation tables for the index are given in Appendix I.

Parameter	Results	(points)
Total Phosphorus (mg/L as P)	0.8	(4)
Soluble Phosphorus (mg/L as P)	1.65	(5)
Organic Nitrogen (mg/L as N)	1.55	(3)
Nitrate Nitrogen (mg/L as N)	1.0	(3)
Ammonia Nitrogen (mg/L as N)	0.95	(4)
% Dissolved Oxygen saturation at 5 ft	110%	(0)
% Water Column with at least 0.1 ppm D.O.	100%	(0)
Light penetration (Secchi disk)	2.83	(6)
Light transmission (% at 3 ft)	14%	(4)
Total plankton per liter	532,039/L	(25)
Bluegreen dominance	Yes	(10)
TOTAL EUTROPHY POINTS		64

Table 4.9. Comparison of IDEM Eutrophy Index parameters in three years (1974, 1990, 1992).

Date:	7/23/74		7/2/90		6/25/92	
Parameter	value	(pts)	value	(pts)	value	(pts)
Total P	0.17	(3)	0.06	(3)	0.8	(4)
SRP	0.035	(1)	0.17	(3)	0.54	(4)
Organic N	0.57	(1)	1.73	(3)	1.55	(3)
Ammonia	0.17	(0)	0.49	(2)	<0.95	(4)
Nitrate	0.6	(2)	1.5	(3)	<1	(3)
D.O. sat.	124	(2)	115	(1)	110	(0)
D.O. column	55	(2)	90.5	(0)	100	(0)
Secchi disk	2.5	(6)	6.23	(0)	2.83	(6)
Light trans.			37	(3)	14	(4)
Total plankton	49000	(14)	1192747	(25)	532039	(25)
Bluegreen	yes	(10)	yes	(10)	yes	(10)
TOTAL POINTS		41		53		63
TROPHIC CLASS		II		III		III

4.2 STREAM WATER QUALITY

The watershed drains into Big Lake by overland flow and through five stream inlets. Physical and chemical parameters were measured during baseflow in each stream on 8 April 1992 and stormflow on 17 June 1992 after a rainfall of 0.63 inches. The complete set of data are given in Table 4.10.

Table 4.10. Nutrient concentration and turbidity in tributaries to Big Lake during baseflow (8 April 1992) and stormflow (17 June 1992). (TPb=total phosphorus baseflow; TPs=total phosphorus stormflow; TKNb=total Kjeldahl nitrogen baseflow; TKNs=total Kjeldahl nitrogen stormflow; TSSb=total suspended solids baseflow; TSSs=total suspended solids stormflow)

Inlet	TPb	TPs	TKNb	TKNs	TSSb	TSSs
Crooked	0.02	0.4	0.67	1.6	4	<4
Crane	0.02	1.1	1.6	3.0	7	12
Stuckman	0.09	1.1	2.9	12.0	<4	450
Green	0.24	0.9	3.0	6.5	7	<4
Sell	0.08	1.0	2.9	6.2	35	170

These data present only a snapshot of water quality in the streams at a particular time and may not give an accurate picture of overall water quality in these inlets. Furthermore, the baseflow sample was collected in early spring, which is generally a high flow season in Indiana streams. Future studies should include multiple samples to give a measure of variability and should especially involve sampling during the fall season when low flow may concentrate pollutants from point sources.

Nutrient inputs varied among inlets and increased significantly during stormflow, but were not always positively correlated with turbidity. Total Kjeldahl nitrogen at least doubled for all inlets during stormflow with an increase by a factor of six for Stuckman inlet and tripled for Green and Sell inlets (Figure 4.12). Phosphorus levels were strongly enhanced during stormflow to nearly the same concentration in four of the five inlets at approximately 1.0 mg/L (Figure 4.13). Phosphorus concentration in Crane and Stuckman increased by a multiple of 22 and 11, respectively.

Turbidity in streams may increase during stormflow due to erosion from watersheds, streambanks, and streambed. Three of five inlets did not show an appreciable increase in turbidity, or total suspended solids(TSS), during stormflow. However, erosion appears to be particularly severe in Stuckman at 450 mg/L TSS and in Sell at 160 mg/L TSS (Figure 4.14).

Turbidity in streams can create a source of nutrients, as well as having a direct negative affect on aquatic life. Solids that settle to the stream bottom can blanket gravel bottoms, which are essential as habitat for beneficial algae, aquatic insects, and developing fish eggs. Fry of many fish species feed by sight and cannot find sufficient

Figure 4.12. Total Kjeldahl nitrogen at five inlets to Big Lake, Noble and Whitley counties, during baseflow on 8 April 1992 and stormflow on 17 June 1992.

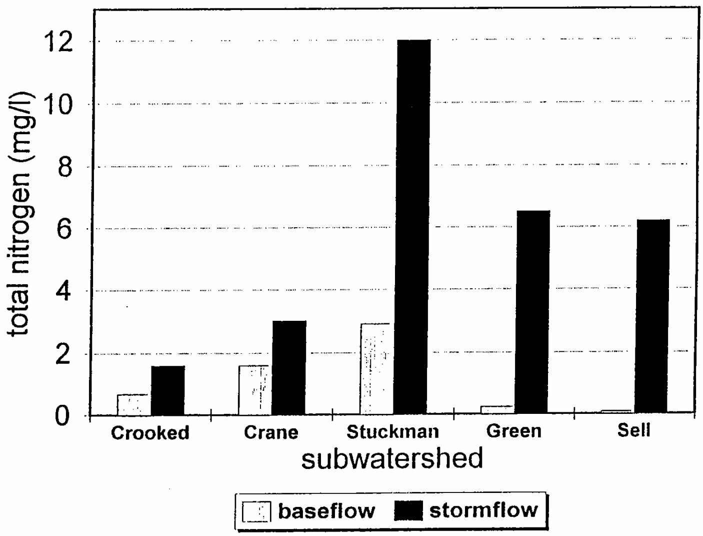


Figure 4.13. Total phosphorus at five inlets to Big Lake, Noble and Whitley counties, during baseflow on 8 April 1992 and stormflow on 17 June 1992.

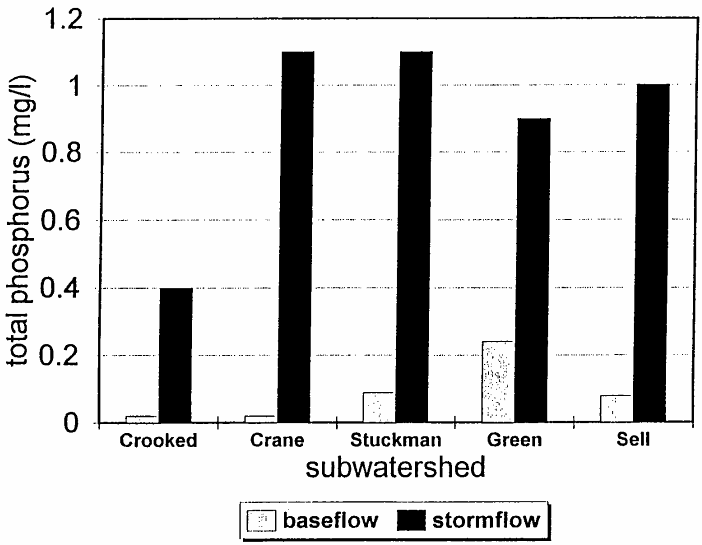
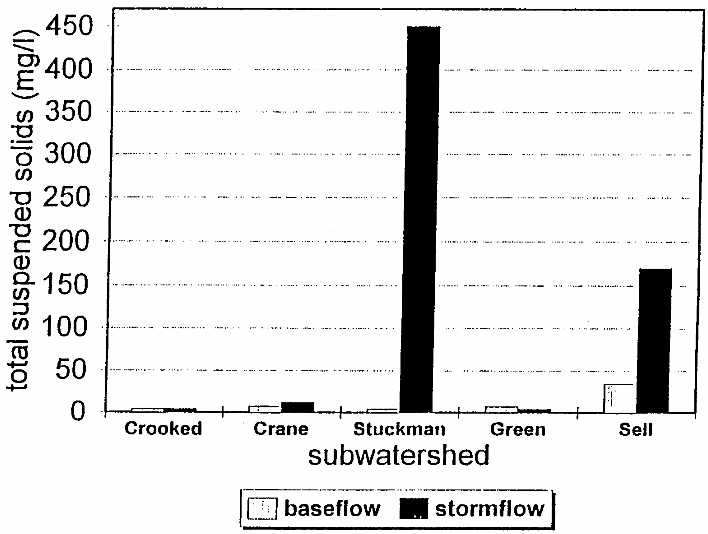


Figure 4.14. Total suspended solids (TSS) at five inlets to Big Lake, Noble and Whitley counties, during baseflow on 8 April 1992 and stormflow on 17 June 1992.



food under turbid conditions. Suspended materials can clog gills of insects, mussels, and fish.

Turbidity can be directly related to fish production. During baseflow, only Sell ditch maintains a level of suspended solids that could reduce fish production, according to a scale designed by Alabaster and Lloyd in 1980 (Table 4.11). Levels during stormflow are high enough in Stuckman to indicate poor conditions for fish and in Sell to be unlikely to support good fisheries. Long-term effects of periodically high turbidity are difficult to predict.

Table 4.11. Relationship between total suspended solids (TSS) and fish production (Alabaster and Lloyd 1980).

TSS	fish production
< 25 mg/L	no harmful effect on fisheries
25-80 mg/L	may reduce fish production
80-400 mg/L	unlikely to support good fisheries
> 400 mg/L	poor fisheries conditions

Certain nutrients and toxins attach readily to sediment. In Stuckman and Sell, nutrient inputs may be reduced by controlling sources of sedimentation. However, nutrients and toxins are not necessarily carried by sediment and can be transported as dissolved substances in the water. Phophorus levels were relatively high in Crane and Green subwatersheds, even though sediment in the water was low. Of the total phosphorus in Crane Lake in July of 1991, six percent was soluble reactive phosphorus in the epilimnion and 96 percent was in the soluble state in the hypolimnion. Data from Crane Lake also indicated 91 percent of the total phosphorus in this tributary lake was associated with deeper water (hypolimnion).

Therefore, much of the phosphorus contributed by tributaries from Crane Lake was dissolved phosphorus that was probably either derived from organic material (algae, sewage, or animal waste) in the water column or was resuspended from the sediments due to low dissolved oxygen levels in water deeper than six feet. The same situation may exist in the Green Lake tributary.

Inlets from both Crane and Green subwatersheds flow through small lakes that could be acting as sediment traps for Big Lake. Future studies might include conductivity measurements in order to address the dissolved or suspended state of pollutants and method by which nutrients are transported in each stream system. In addition, water quality testing above and below Crane and Green Lakes would indicate whether these waters are functioning as sediment basins.

Section 5.0 POLLUTANT SOURCES

Pollution can enter a lake from either point or nonpoint sources in a watershed. Mathematical models can be used to predict approximate pollutant loads. Phosphorus loading in Big Lake from nonpoint sources was estimated using the unit area loading (UAL) approach (U.S. EPA, 1980). The predicted in-lake concentration of phosphorus was in the range of 0.06-0.58 mg/L with 0.22 mg/L being most likely. The vast majority (88 percent) of phosphorus from the watershed is probably derived from rowcrop land use (Figure 5.1). Septic systems were predicted to be the second most important source of phosphorus at 5.6 percent. Crane and Sell together were estimated to contribute the majority (68 percent) of the phosphorus to Big Lake from subwatersheds (Table 5.1; Figure 5.2).

Table 5.1. Probable subwatershed contributions to phosphorus loading using the unit area loading (UAL) model for Big Lake.

Subwatershed	Phosphorus loading (g/m2/yr)	(percent)
Big Lake	0.28-0.54	8%
Green	0.51-0.80	12
Stuckman	0.68-0.78	12
Sell	1.45-2.14	32
Crane	1.70-2.39	36
TOTAL	4.62-6.65	100

Because this study produced only preliminary information, sources of sediments and nutrients within each watershed can only be estimated from field and land use information. The following descriptions of potential sources are meant to be guides for further investigation. Subwatersheds are listed in a prioritized order according to field results and modelling, starting with those that apparently have the most negative effect on water quality in Big Lake. Equations and complete calculations for the lake phosphorus model are given in Appendix II.

Big Lake vicinity

Residential development is of primary concern for controlling factors immediately around Big Lake that could affect water quality. Septic systems and lawn fertilizers in dense residential areas may supply nutrients through leaching and runoff. The small amount of row crops on the southwest side of the lake are nearly completely separated

Figure 5.1. Predicted phosphorus contributions of land use types to Big Lake according to the unit area loading (UAL) model.

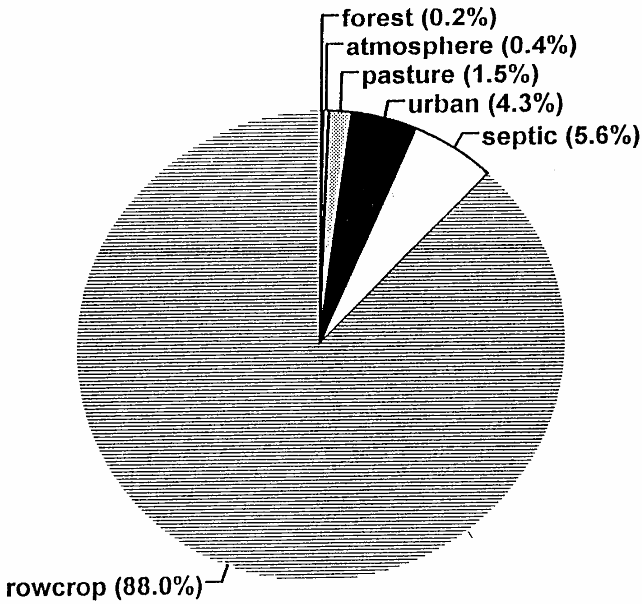
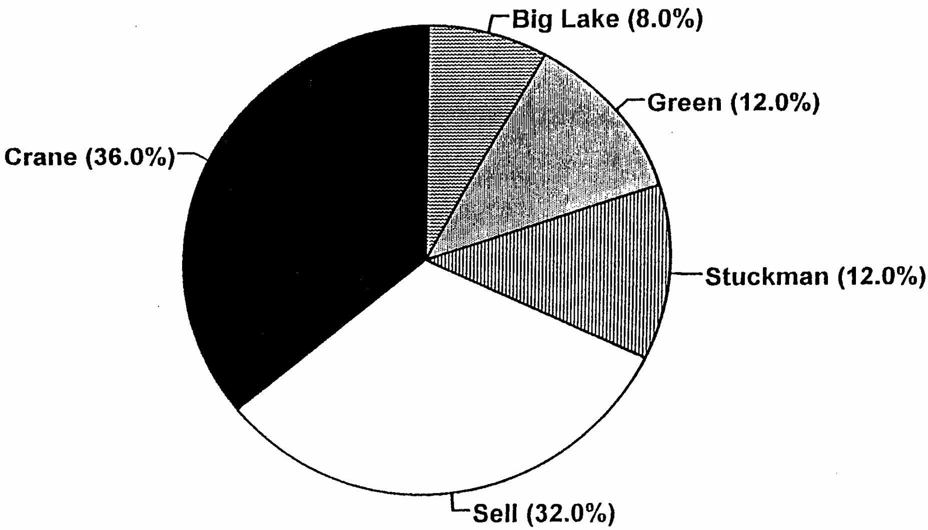


Figure 5.2. Predicted phosphorus contributions of subwatersheds to Big Lake according to the unit area loading (UAL) model.



from the lake shore by forests or wetlands that probably absorb nutrients and sediment in runoff.

Stuckman Branch subwatershed

Modeling and field testing in the Stuckman Branch subwatershed showed conflicting results. Modeling of Stuckman Branch predicted relatively low phosphorus contributions. However, field testing showed that the inlet had the highest levels of phosphorus, nitrogen, and sediment of any inlet during stormflow. This subwatershed has only a very small amount of highly erodible soils, but is nearly completely row cropped. Erosion problems from fields, residential construction or streambanks may be the source of nutrient and sediment contributions.

Crane Lake subwatershed

Sediment from the relatively large agricultural acreage over highly erodible soils likely settles in Crane Lake. Outflow from the lake acts as a primary source of nutrients, but relatively little sediment for Big Lake. Currently, corn and beans are planted very close to the roads in some areas. Erosion in cropland east of C.R. 250W may be contributing to filling of roadside ditches in this region. Streams entering and leaving Crane Lake appear to be highly channelized. Failing septic systems in residential zones along lower reaches of the Crane Lake outlet may be the major source of high phosphorus levels.

Sell Branch subwatershed

Sell Branch drains a subwatershed with the most diverse combination of land uses and largest acreage of highly erodible soils. Upper reaches of the subwatershed contain significant residential acreage. Several potentially high quality wetlands remain in the watershed and probably act as important nutrient and sediment traps. Streambank erosion appears to be a problem in some areas and may be the major source of sedimentation during stormflow. Livestock and manure management practices may exacerbate nutrient levels in this watershed.

Green Lake subwatershed

Only a very small amount of siltation occurs during stormflow in the Green Lake subwatershed, probably because much of the land area is protected from erosion by wetlands, forest, and pasture land. In addition, very little of the region contains highly erodible soils. Both nitrogen and phosphorus inputs are intermediate for the region, but particular sources of nutrients were not discovered. Only one potential problem was indicated by field reconnaissance. Land along the row crop field south of Green Lake on the north side of C.R. 500S may introduce sediments and nutrients to the ditch. High nutrient levels, in combination with low sediment levels, indicate the possibility of inputs from failing septic systems.

Crooked Lake subwatershed

The outlet of Crooked Lake supplies relatively insignificant amounts of sediment and nutrients to Big Lake. Sediments that do enter Crooked Lake may settle out before reaching the outflow to Big Lake. Phosphorus and nitrogen inputs double during stormflow, but remain at less than half the levels of any other inlet. Septic systems in residential areas around the lake may constitute the major source of nutrient input to the lake.

Several factors related to topography and land use probably prevent Crooked Lake from receiving large amounts of sediment. First, the land area of the watershed is small relative to the lake size. Second, much of the subwatershed is crossed by forest or vegetative cover. A single small intermittent stream feeds Little Crooked Lake. Although there are a number of houses immediately around much of Crooked Lake, the entire length of the intermittent stream, most of the steep areas to the south and east of Little Crooked Lake, and nearly the entire shore of Crooked Lake are forested.

Section 6.0 MANAGEMENT IMPLICATIONS

Land use in the Big Lake watershed is typical of most lake watersheds in northern Indiana. Agriculture is the dominant land use, heavy development is increasing around the lake, and artificial drainage has been provided over time to allow for more farming and development.

In most years, water quality in Big Lake compared unfavorably to the average lake in Noble and Whitley counties. Information available for this study indicated a general trend towards deteriorating water quality over the past 30 years with a sharper drop occurring since 1990. Further residential development and farming practices in the watershed should be carefully monitored to ensure that water quality is maintained at the highest possible level.

State and federal programs could be utilized to promote resource conservation practices. Educational materials related to the current status of the lake and improvements possible through best management practices (BMPs), such as conservation tillage and erosion control, should be available to rural and urban residents. The Noble and Whitley County Soil and Water Conservation Districts (SWCD) are currently seeking funding for watershed treatment, including increased conservation and no-till farming (Michael Martin, Big Lake Association, pers. comm.).

This study was conducted to give a preliminary picture of general watershed conditions in the Big Lake area. The following recommendations indicate a course of action that would most likely improve water quality, regardless of the results of more accurate monitoring. Longer-term periodic monitoring of lakes and tributaries in the watershed would be necessary to accurately determine the most efficient use of resources for improving the current poor status of water quality in Big Lake. Subwatersheds are listed in the same order used in the previous section.

6.1 IN-LAKE RESTORATION

Lake restoration can include manipulation of physical, chemical, and biological characteristics. Possible avenues for restoration are detailed below.

6.1.1 Lake Sediment Analysis

Recent high levels of phosphorus in the hypolimnion of Big Lake create an unusual situation for reducing problems caused by nutrients. Contributions of phosphorus due to agricultural runoff and residential sewage can be controlled by stabilizing soils, creating detention basins, filtering water through wetlands, and improving on-site wastewater treatment. However, initial data from this study suggests that a large proportion of the phosphorus in the lake is now associated with the lake bottom. For this reason, the lake association may choose to avoid restoration strategies that could stir up bottom sediments and resuspend phosphorus in the water column.

Sediment analysis for total phosphorus and total nitrogen would be useful in determining a future course of action. Reduction of external sources of phosphorus may not produce a noticeable improvement in water quality because of internal loading, or release of stored phosphorus from the lake bottom. Several options exist for limiting internal loading. However, treatments indicated below will not produce long-term beneficial results unless external sources are also controlled.

Sediments can be treated within the lake by chemical means. Aluminum oxides (alum) will bind phosphorus and eventually create a seal over the sediments. Alum treatments can be applied directly to the lake or injected into inflows. Alum can be potentially toxic under acidic conditions, but is less likely to cause a problem in the well-buffered lakes of Northern Indiana. Sediment oxidation with calcium nitrate injection or aeration of the hypolimnion will also prevent release of phosphorus by increasing oxygen levels at the lake bottom.

Sediments can be physically removed from the system. Sediment skimming (dredging) is a more costly approach, but also serves to deepen the lake where infilling has occurred. Care must be taken not to exacerbate nutrient problems by resuspending dredged materials in the water column through improper removal or disposal techniques.

On a smaller scale, residents could limit activities that disturb bottom sediments in near-shore areas during recreational activities and construction projects. For instance, high speed boating and heavy boat traffic in shallow areas of northern Indiana lakes can stir sediments and create severe turbidity problems.

Prior to selecting any type of in-lake restoration, further study may be helpful. Sediment samples should be analyzed for phosphorus content from major bay areas in the lake. Water quality monitoring at the outflow would indicate how much of the sediment and nutrient load remain in the lake as opposed to being flushed from the system. Knowing the current water renewal time for the lake would help in determining the efficacy of various types of in-lake treatments for enhancing water quality. Additionally, a current bathymetric map would indicate location and rate of sediment settling in the lake and give a more accurate picture of sediment contributions of each inlet.

6.1.2 Aquatic Plant Management

Carefully planned management of aquatic plants can be employed to prevent spread of exotic species and enhancement of beneficial native species. Control of expanding exotic plant populations could decrease interference with recreation and enhance habitat for wildlife.

Exotic populations appear to be most dense near residential development. Overgrowth of milfoil currently exists in the basin to the north of the inlet from Crane Lake and shallow areas on the west side of the southern point into Big Lake (Michael Martin, pers. comm.). Application of herbicides that are approved for use in waterways may be the best option for eliminating dense stands of exotic plants. Widespread application is not recommended due to effects on beneficial native plants.

Once exotic plants have become established, control is very difficult. Therefore, preventing the spread of such plants is the most effective strategy. Several species of exotic plants reproduce very effectively by "vegetative propagation." New plants can sprout from thousands of broken stem fragments that result from mechanical clearing for beaches, docks, and landings. Boating through stands of aquatic plants can result in spread of nuisance species by chopping and carrying plant pieces within and between lakes. Overzealous control of emergent native plants between 1963 and 1980 may have created empty space along shorelines, so that exotic submergent species could invade.

Removal of native plants for recreational purposes should be limited as much as possible in Big Lake, especially around the west basin of the lake where native diversity is high and exotics are not well-established. This area is less residential and could be maintained in a more natural state without interfering with most of the recreational use of the lake.

Where plants must be removed, mechanical harvesting is a preferred method for control of native plant growth. Decomposing plants are unsightly, contribute nutrients to the lake, and decrease oxygen levels. Therefore, harvested material must be collected. Disposal of harvested plants in locations that are not wetlands and in areas which do not have a direct water connection to the lake in order will help prevent spread of the exotic plants.

Overgrowth by aquatic plants results in partial response to additional nutrients in the water. At high nutrient levels, removal of aquatic plants increases light levels and nutrients available for growth of algae. Conversely, increased water clarity enhances growth of aquatic macrophytes. Only by controlling phosphorus and nitrogen flows into the lake can plant and algae growth both be expected to decrease in the long run.

6.1.3 Fishery Management

Sportfish conditions in Big Lake are stable with good growth of bluegill. Concerns about fishing pressure on largemouth bass in the 1980s (Pearson 1987; Pearson 1980) led to implementation of a 12-inch size limit on bass at Big Lake and all other natural lakes in northern Indiana which had no previous size limit in 1990. In addition, IDNR fisheries reports suggested encouraging anglers to target other species, such as crappie or perch could reduce stress on largemouth bass populations (Pearson 1980). Bass densities appear to be increasing since implementation of the size limit (Jed Pearson, Division of Fish and Wildlife, IDNR, memo, May 1, 1995).

Extensive sampling in 1990 indicated that there was not a shortage of quality-sized largemouth bass relative to other lake fish populations in the region. Sampling in the spring of 1990 showed a catch rate of 8-inch and larger bass of 121 fish/hour, which was well within the normal range for natureal lakes (94/hr, SD=50). The catch rate of 14-inch and larger bass (41/hr) was over three times greater than the mean for natural lakes (12/hr). The catch rate of 18-inch and larger bass (2.8/hr) was slightly greater than the natural lake mean (2.4/hr). Data collected in earlier surveys may have reflected seasonal biases in electrofishing methods.

During the 1963 survey, anglers reported periodic catches of northern pike, although none were collected by fisheries managers. Stocking hybrid muskies or northern pike could benefit the fishery by establishing another predator (Pearson 1987). However, a recent 8-year study in Skinner Lake determined that stocking pike may only be minimally successful as a predatory management tool in northern Indiana lakes.

Northern pike is not known to be a native species of Big Lake or any other lakes within the upper reaches of the Tippecanoe River watershed and has not been legally stocked in these lakes during the last 25 years. Pike do exist in Lake Tippecanoe. The current position of IDNR is that there is "no need to increase the supply of northern pike in northern Indiana" and there is no intention of stocking pike in these lakes. However, nearby Loon Lake in Whitley/Noble counties has been stocked with hybrid muskies and local anglers have reported an occasional muskie catch at Big Lake (Jed Pearson, Division of Fish and Wildlife, IDNR, memo, May 1, 1995).

6.2 SUBWATERSHED LAND TREATMENT

Each subwatershed within the Big Lake area contributed differently to the pollution load of the lake. Suggestions for management given below include land use practices that are targeted to specific factors that appeared to be a problem in that subwatershed. Further study might include modeling of soil loss to determine sediment retention and filling rates of small lakes on inlets to the lake.

Big Lake vicinity

Residents along the lake shore can work towards improved water quality through proper management of their landscapes and beaches. Revegetation of wetland areas in idle lands around the lake and planting of vegetated buffer strips between houses and the lake would reduce nonpoint source pollution of Big Lake.

Appropriate use of lawn fertilizers includes applying only the necessary amount during the spring, when growing plants are more likely to take up the chemicals. When dumped into streams and lakes, grass clippings and leaves decompose, consuming oxygen and releasing unnecessary nutrients. Where possible, lawn clippings and leaves should remain on the grass by using a mulching mower blade or be placed in compost bins. Nutrients provided by mulching can reduce the amount of artificial fertilizers that need to be applied for lawn maintenance.

Compared with Crooked Lake, very little of the shoreline around Big Lake is forested. Trees along the south shore of a lake are particularly useful for shading water and retarding growth of rooted aquatic plants in near-shore areas, where recreational activities may occur (Summerfelt 1993). In addition, downed trees and brush create significant cover for spawning and concentrate fish for anglers. Windbreaks around the periphery of the lake, especially on the north and west sides, create areas of calmer water for shallow-water fish spawning and comfortable fishing on sunny or windy days.

Proper repair of septic systems may be difficult due to spatial and geological conditions. Soils surrounding the lake are considered to be severely limiting for on-site septic systems. Adequate space does not exist for siting new or upgraded systems in current residential areas. Poor filtering capacity of soils and high water tables restrict efficiency of septic systems around the lake.

Due to the density of septic systems and increasing use of properties from seasonal to year-round habitation, managing waste water is a major concern of the lake association. Water quality and disease transmission related to inadequate sewage disposal may affect quality of life and property values in the area. Several solutions to these problems are under discussion by the lake association.

The scope of this study precluded a thorough determination of the options available for human waste disposal, including possible development of a sewage system and small treatment plant. The area around Big Lake has recently been annexed into the Tri-lakes regional sewage district and plans are underway for a treatment system that would encompass Big Lake, New Lake, and Loon Lake in Noble and Whitley counties (Michael Martin, pers. comm.). Future studies could include a determination of the level of bacteriological contamination at various locations around the lake.

Stuckman Branch subwatershed

The unusually high levels of suspended solids in stormflow warrant further investigation into agricultural practices. Control of streambank erosion, implementation of conservation tillage, and installation of sediment traps will most likely improve water quality in this subwatershed. Conversion of cropland along the ditch to Conservation

Reserve Program or at least creation of vegetated filter strips may also reduce the inordinately high levels of siltation in the outflow to Big Lake.

On October 15, 1992, personnel from the Division of Soil Conservation, Indiana Department of Natural Resources, surveyed several potential sites for sediment retention structures in this subwatershed. Descriptions of the two most likely sites are as follows:

1) Site located immediately upstream (east) of S.R. 109 drains 420 acres, or 79 percent of the total drainage area of the subwatershed. Installation of a sediment trap would cost in the range of $5,000-10,000. Maintenance would require an access road from S.R. 109.

2) Site located at the outlet of Stuckman Drain would add about 110 acres to the aforementioned site and cover 100 percent of the total drainage area. Although this structure covers a small drainage area, the drain runs alongside S.R. 109 for 1,500 feet and may pick up sediment and contaminants associated with winterizing salt and road traffic.

<u>Crane subwatershed</u>

Crane Lake apparently acts as a sediment retention basin for this subwatershed. The lake should be monitored to determine the rate of filling. Above Crane Lake, addition of vegetated buffer zones along roadside ditches and the stream may slow soil erosion and chemical loss from these row crop lands. Conversion of pasture to crops would probably exacerbate erosion in the watershed because of highly erodible soils, although these areas lie at a distance from the stream itself. Forested areas along upper reaches of the Crane Lake outlet probably filter sediment and nutrients and should be protected from further development. Idle lands along the southern bank of the outlet could be reforested. Activities which disturb the sediment or reduce oxygen levels in the lake should be avoided to limit resuspension of phosphorus in deeper water. Septic systems in residential zones along the lower reaches of the outlet should be examined for leaching.

<u>Sell Branch subwatershed</u>

Mixed land use in Sell Branch subwatershed requires a combination of land treatment approaches. Use of filter strips along ditches and around areas with confined livestock would limit soil erosion. Installation of sediment traps on Sell Branch upstream of C.R. 600 (Airport

Road), S.R. 109, and County Line Road may significantly reduce sediment input to the lake. Reconnaissance by the Division of Soil Conservation, Indiana Department of Natural Resources, indicated the following possible costs that would be incurred and coverage of these sediment traps:

1) Site located immediately upstream of C.R. 600 N and alongside Airport Road: The drainage area contributing to this site is about 540 acres, or about 36 percent of the total. Installation costs would be in the range of $5,000-10,000. Maintenance access would be from Airport Road.

2) Site located about 600 feet upstream from S.R. 109: The additional drainage area is about 320 acres, or coverage of 57 percent of the total drainage area. Installation cost would range from $5,000-10,000. An access site would have to be created for maintenance.

3) Site located immediately upstream of County Line Road: Additional drainage area is about 380 acres, or 82 percent of the total. Installation cost should range from $5,000-10,000 with maintenance access from County Line Road.

Significant wildlife habitats are apparent in the upper watershed. Forested lands are mostly over highly erodible soils and should be maintained in their current use. Wetland areas should be protected for filtering nutrients and trapping sediments. The wetland north of C.R. 600N is connected to Crooked Lake by a large tract of forest and may respond well to restoration efforts, as it provides a mixture of habitat types and access to water for area wildlife. An additional region in the headwaters across Airport Road also appears to be a large remnant of forested wetland. Voluntary protection of these two zones should be a high priority.

<u>Green Lake subwatershed</u>

Of all the subwatersheds, the Green Lake region is currently in the best condition relative to nutrient and soil retention and contains several large natural areas . Current uses in pasture, wetland, and forested areas should be protected. Wetland areas around the Green Lake outlet provide the only significant natural buffer zone for Big Lake. Idle land to the southeast of Green Lake and south of C.R. 500S has the potential for being prime wildlife habitat, as it could significantly expand wetland areas along Big Lake. Encroachment of residential zones from the east and northwest should be carefully controlled. Septic systems at nearby residences should be examined for signs of failure and repaired where indicated.

Crooked Lake subwatershed

Because this study was conducted under the auspices of the lake association around Big Lake, the Crooked Lake subwatershed was not a primary focus for this study. However, cooperation between residents at both lakes would be beneficial in maintaining the current relatively low level of sediment and nutrient inputs to Big Lake. Critical areas of the watershed should remain forested, particularly along steep slopes, streambanks, and lake shores. Evaluation and maintenance of septic systems near the lakes will ensure that nutrient inputs remain low or decrease.

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APPENDIX I

Calculation of the Eutrophication Index (IDEM, 1986).

Low eutrophy points indicate a range that is typical for a high quality or low productivity (oligotrophic) lake. High eutrophy points indicate a range that is typical for a low quality or highly productive (eutrophic) lake.

Parameter and Range	Eutrophy Points
I. Total Phosphorus (ppm)	
A. At least 0.03	1
B. 0.04 to 0.05	2
C. 0.06 to 0.19	3
D. 0.2 to 0.99	4
E. 1.0 or more	5
II. Soluble Phosphorus (ppm)	
A. At least 0.03	1
B. 0.04 to 0.05	2
C. 0.06 to 0.19	3
D. 0.2 to 0.99	4
E. 1.0 or more	5
III. Organic Nitrogen (ppm)	
A. At least 0.5	1
B. 0.6 to 0.8	2
C. 0.9 to 1.9	3
D. 2.0 or more	4
IV. Nitrate (ppm)	
A. At least 0.3	1
B. 0.4 to 0.8	2
C. 0.9 to 1.9	3
D. 2.0 or more	4
V. Ammonia (ppm)	
A. At least 0.3	1
B. 0.4 to 0.5	2
C. 0.6 to 0.9	3
D. 1.0 or more	4
VI. Dissolved Oxygen (percent saturation at 5 feet from surface)	
A. 114% or less	0
B. 115% to 119%	1
C. 120% to 129%	2
D. 130% to 149%	3
E. 150% or more	4

Calculation of Eutrophication Index (cont.)

VII. Dissolved Oxygen (percent of water column with at least 0.1 ppm DO)		
A.	28% or less	4
B.	29% to 49%	3
C.	50% to 65%	2
D.	66% to 75%	1
E.	76% to 100%	0
VIII. Light Penetration (Secchi Disc)		
A.	Five feet or less	6
IX. Light Transmission (photocell percent at depth of 3 feet)		
A.	0 to 30%	4
B.	31% to 50%	3
C.	51% to 70%	2
D.	71% and up	0
X. Total plankton per ml (one vertical tow from depth of 5 feet)		
A.	Less than 500/ml	0
B.	500 to 1,000/ml	1
C.	1,000 to 2,000/ml	2
D.	2,000 to 3,000/ml	3
E.	3,000 to 6,000/ml	4
F.	6,000 to 10,000/ml	5
G.	More than 10,000/ml	10
H.	Blue-green dominance	5 additional points
(one vertical tow from depth of 5 feet that includes the beginning of the thermocline)		
A.	Less than 1,000/ml	0
B.	1,000 to 2,000/ml	1
C.	2,000 to 5,000/ml	2
D.	5,000 to 10,000/ml	3
E.	10,000 to 20,000/ml	4
F.	20,000 to 30,000/ml	5
G.	More than 30,000/ml	10
H.	Blue-green dominance	5 additional points
I.	100,000 or more	5 additional points

APPENDIX II

Big Lake Phosphorus Model - Equations.

1) Estimation of Lake Phosphorus Concentration (P):

P=L/(11/6 + 1.2 * qs)

Where: P = Lake phosphorus concentration (mg/L)
L = Phosphorus loading (g/sq m-yr)

2) Estimation of Areal Water Loading (qs) for Big Lake:

Q = (Ad * r) + (Ao * Pr)
and
qs = Q/Ao

Where: Q = Inflow water volume (cu m/yr)
Ao = Lake surface area = 858,300
Ad = Contributing watershed area(sq m)= 22,680,162
r = Total annual unit runoff (m/yr) = 0.2794
Pr = Mean annual net precipitation (m/yr) = 0.914

Q = 7,905,809 cu m/yr
qs = 9.211 m/yr

3) Estimation of Areal Phosphorus Loading (L) for Big Lake:

M = (Er * Ar) + (Ef * Af) + (Ea * Aa) + (Ew * Aw) +
(Ep * Ao) + (Es * C * (1-Ks))
and
L = M / Ao

Where: M = Total phosphorus mass loading (kg/yr)
Er = P export coefficient for residential land (kg/ha-yr)
Ar = Area of residential land (ha)
Ef, Af = forest land
Ea, Aa = agricultural land
Ew, Aw = wetland
Ep = P export coefficient for precipitation
Es = P export coefficient for septics (kg/C-yr)
C = number capita-years serviced by septics
Ks = Soil retention coefficient

Big Lake Phosphorus Model - Calculations

Sources	Area		Phosphorus Export Coefficients Low	Likely	High
Forest	183	ha	0.025	0.035	0.090
Agriculture					
rowcrop	1,205	ha	0.94	3.14	8.6
pasture	258	ha	0.14	0.25	0.85
idle	41	ha	NA	NA	NA
Urban	169	ha	0.35	1.1	2.7
Septics	1,071	cap-yr	0.002	0.3	0.6
Precipitation	86	ha	0.125	0.2	0.31

Sources	Area		Phosphorus Mass Loading Low	Likely	High
Forest	183	ha	4.58	6.41	16.5
Agriculture					
rowcrop	1,205	ha	1,133	3,784	10,363
pasture	258	ha	36.1	64.5	219
idle	41	ha	NA	NA	NA
Urban	169	ha	59.1	185.9	456.3
Septics	1,071	cap-yr	1.93	241.0	321.3
Precipitation	86	ha	10.7	17.2	26.6
Total Phophorus Mass Loading (M) (kg/yr):			1,246	4,300	11,406

Big Lake Phosphorus Model - Calculations (continued)

Sources	Area	Phosphorus Mass Loading Low	Likely	High
Crane Subwatershed				
forest	63.2	1.58	2.21	5.69
rowcrop	472.9	444.5	1,485	4,068
pasture	93.9	13.1	73.7	79.8
urban	22.7	7.95	25.0	61.3
TOTAL (Crane)		467	1,535	4,214
Stuckman Subwatershed				
forest	14.2	0.355	0.497	1.28
rowcrop	182.6	172	573	1,570
pasture	10.9	1.53	2.73	9.27
urban	5.6	1.96	6.16	15.1
TOTAL (Stuckman)		175	582	1,596
Green Subwatershed				
forest	21.9	0.548	1.96	1.97
rowcrop	131.9	124	414.2	1,134
pasture	50.2	7.03	12.6	42.7
urban	12.6	4.41	13.9	34.0
TOTAL (Green)		136	441	1,213
Sell Subwatershed				
forest	74.5	1.86	2.61	6.71
rowcrop	370.4	348.2	1,163	3,185
pasture	90.7	12.7	22.7	77.1
urban	48.2	16.9	53.0	130.1
TOTAL (Sell)		380	1,241	3.399
Big Lake Vicinity Subwatershed				
forest	8.9	0.223	0.312	0.801
rowcrop	46.9	44.1	147.3	403.3
pasture	12.1	1.69	3.03	10.3
urban	80.2	28.1	88.2	216.5
TOTAL (Big Lake vicinity)		74.1	239	631

	Low	Likely	High
Areal Phosphorus Loading (L) (g/sq m/yr):	1.45	5.0	13.3
Lake Phosphorus Concentration (P) (mg/L):	0.06	0.221	0.587